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1830

FAMILIAR ILLUSTRATIONS

OF

NATURAL PHILOSOPHY.

SELECTED PRINCIPALLY FROM

DANIELL'S CHYMICAL PHILOSOPHY.

BY JAMES RENWICK, LL.D.,

PROFESSOR OF NATURAL EXPERIMENTAL PHILOSOPHY AND
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PREFACE.

In undertaking, at the request of the publishers, to select from a number of English works one which would serve as an introduction to natural philosophy, suited to the purposes of the School District Library, great difficulty was experienced in the choice. Of the books submitted by them, some were too difficult to be understood, while those of a more popular character were deficient in scientific accuracy, or behind the present state of knowledge. While thus engaged, an "Introduction to the Study of Chymical Philosophy," by Professor Daniell, of London, came, by the politeness of its author, into the hands of the editor. On perusal, it appeared, although intended for a far different purpose, to contain matter in the very form and of the very description which was wanted. While, therefore, an apology may seem due to that learned gentleman for stripping his work of the very parts which constitute its direct object, the editor feels satisfied that he is presenting to the American public the most lucid composition of the leading facts and principles of natural philosophy which has yet appeared in the English language.

In adapting the work of Professor Daniell to the present object, all that was strictly chymical has been omitted, and with it the exposition of the views of Faraday in relation to the connexion of electricity with chymical affinity. Some few alterations have been made in the text to adapt it to the American reader, and a variety of additions have been introduced to render the work more general and popular in its character. The most considerable of these have reference to magnetic and optical instruments, and to acoustics.

J. R.

Columbia College, Oct., 1839.

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NATURAL PHILOSOPHY.

§ 1. EXPERIENCE, or the repeated evidence of our senses, and an irresistible belief that "like causes will ever produce like effects," constitute the sound foundation of natural knowledge.

The convictions arising from these impressions have directed the intellect of man, in all ages and in all stations, to control the powers which have been imparted to the material universe to his own advantage; the maintenance of a bare existence in savage life being no less dependant upon them than are the polished arts of civilized society. It is strange, however, to remark how long a time elapsed, even in a state of high intellectual culture, before it was discovered that the same principles which teach the mere child that fire will burn, that water will flow, and that a moving stone will inflict a blow, and to guide his conduct accordingly, would lead to that higher acquaintance with the powers of nature which we distinguish by the title of *natural philosophy*. The powers of reason had been exercised with success upon abstract science for ages before the voice of Bacon proclaimed, and insisted earnestly upon, the advantages of extending experience by experiment, and of adopting the accurate observation of *phenomena* as the only safe guide in *physical* investigations; but from the moment that this course was entered upon by the patient student of nature, natural science has advanced with a constantly accelerating progress, extending the power of mind over the forces pertaining to matter in a corresponding degree.

It deeply concerns the student who proposes to himself to enter upon any branch of such investigations, that he should have a right perception of these truths; that he should correctly distinguish the difference between abstract and natural science, and clearly perceive the road along which his course must tend.

The contrast of these two great divisions of science has been forcibly represented by one of the living masters of both. "A clever man," Sir John Herschel has observed,* "shut up alone, and allowed unlimited time, might reason out for himself all the truths of *mathematics*, by proceeding from those simple notions of space and number, of which he cannot divest himself without ceasing to think; but he could never tell, by any effort of reasoning, what would become of a lump of sugar if immersed in water; or what impression would be produced on the eye by mixing the colours of yellow and blue."

§ 2. Experience, then, must be his guide; not the mere passive experience of observation, but the active experience of experiment: that is, he must not only carefully observe *phenomena* as they spontaneously present themselves to him in the ordinary course of nature, but he must purposely contrive and vary circumstances, in order that he may observe them.

To personal experience he must also add the well-attested experience of others; and the experience of past ages as well as of the present; and as, by following this course, the generality of mankind attain to such an acquaintance of the properties of matter as ensures their comfortable existence, with which sensual object they are content; so he has but to persevere in the same, and it will lead him to that intimate knowledge of the order of creation which constitutes science, and which is an object of ambition worthy of a rational creature.

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* HERSCHEL's Discourse on Natural Philosophy, p. 76.

The immediate wants of their nature early taught the human race to direct the agency of *heat* to their supply; and the accumulated experience of ages widely diffused, has given the most unreflecting a command over that principle, which strongly contrasts with the general ignorance concerning the no less general and powerful principle of *electricity*, the very existence of which could scarcely be said to have been recognised till within the last century. When well-directed observation shall have been brought to bear upon this all-pervading power as upon the former, it is scarcely possible to indulge too sanguine hopes of the practical advantages which may flow from such extended knowledge. The forces of nature, indeed, are the powerful, but submissive servants of man, and through their agency, he has been endowed with a subordinate power of creation; but their respective actions have been limited by laws which cannot be transgressed; and in a knowledge of these limits consists the secret of their application.

§ 3. There are two great mistakes which are commonly committed by those who enter upon a systematic course of *physical* inquiry; and not only by those who are commencing, but by those who undertake to direct such studies: the first is, the neglecting to form a proper connexion with previously acquired knowledge, the undervaluing the results of their ordinary experience as parts of the system, as the first rounds of that intellectual ladder by which they aspire to scale the loftiest heights of philosophy: and the second is, the substitution of names for things, the vague acquirement of certain terms, certain forms of expression, instead of a real understanding of objects and principles to which they have been applied: "terms of ignorance and of superficial contemplation," as Lord Bacon calls them.

The process may be repulsive to the too common self-sufficiency of imperfect knowled invited to reflect and reason upon the vations of childhood (simple indeed, l easy than those which he will be call gressively to make), the student oug more offence than when, in the outset *rical* studies, he is referred to the ax evident truths, that "things equal to equal to one another," and "the whole i its parts." It is from the known that h to the unknown; and it is all-important his footing sure, and miss no step by t

§ 4. Something more, in fact, is ne the mere observation of phenomena; t a process of reflection upon the evi senses: the foundation must be crown perstructure of thought and reason.

Professor Whewell, in his recent *Inductive Sciences*, has accurately ren "two things are requisite to the forn ence, facts and ideas; observations o *out*, and an *inward* effort of thought; words, *sense* and *reason*. Neither of th by itself, can constitute substantial ge edge." It is owing to a defect in thi cess that different arts have often attai siderable degree of perfection long could be said to form parts of a gen of science. The chymical arts of metallurgy, dyeing, and many others, to the ancient Egyptians, who probably ignorant of the principles of chymica

The aim of the student, then, must b obtain distinct facts, but clear ideas of ion of these facts. Now it is by thought and operations of mind, whi familiar, that the observations of ex experiment are connected into the ord ture of science [illegible] philosophy are [illegible]

---

* WHEWELL's History of the Inductive Scien

In the ordinary [illegible] with some [illegible]—some [illegible] call them—[illegible] of our experience [illegible] the familiar [illegible] form a conjecture [illegible] tion will include [illegible] we reject it, and we guess again [illegible] in this tentative [illegible] that we have taken a [illegible] The formal course of philosophy differs [illegible] this.

Among a variety of facts or *phenomena* [illegible] together as having some general [illegible] connexion with each other [illegible] is sought which may apply [illegible] planation of all [illegible] or *hypotheses*, are [illegible] er, some with [illegible] success: each after [illegible] want of generality [illegible] length, after [illegible] quirer, the law [illegible] ple which combines [illegible] sive view or *theory*. [illegible] rious process of [illegible] *to* such *laws of nature*, [illegible] guished by their [illegible] and essence.

The full force and range of [illegible] however, only [illegible] their discovery [illegible] employed in the [illegible] resolve the various cases [illegible] posed to be determined [illegible] under their government [illegible] others, which were not [illegible] vestigation. It is then that the most ignorant and simple-minded are capable of understanding what appears to be almost self-evident; and the multitude of such governing principles, so established and registered in her archives, constitutes the great advantage of modern science.

§ 5. In framing the *hypotheses* or suppositions which commonly precede the discovery of the real laws and true theory of phenomena, there is one useful guide which is so often referred to as to render it expedient to explain its nature and appellation, and that is *analogy* or similitude. Design soon becomes apparent in the order of creation; and this design, as far as our limited faculties can trace it, is uniform; and in the system of the universe every part is doubtless proportioned to the whole. No intelligence but that of OMNISCIENCE can comprehend the plan, the *theory* of the universe; but, from the plan of such small portions as have been mastered, we are often enabled successfully to anticipate the order of other portions; and thus to obtain a guide to experiment, to which the ultimate appeal must always be made. *Analogy*, therefore, may serve to suggest and limit *hypotheses;* and of such conditional speculations we have the highest authorty for saying, that "a facility in framing them, if attended with an equal facility in laying them aside when they have served their turn, is one of the most valuable qualities a philosopher can possess."[*]

§ 6. Now, to apply these few plain principles to our present purpose: With regard to precision of terms, the mere enunciation of the object of the following pages will afford us an opportunity of exemplifying and enforcing our meaning; it is an inquiry into THE FORCES OR POWERS OF MATTER. Let us endeavour to ascertain and define the meaning of the expressions MATTER and FORCE: the words are

[*] HERSCHEL'S Discourse.

of common occurrence; but have we that distinct notion of them, those clear ideas concerning their import, which it behooves us to have, in the strict and accurate investigation upon which we are about to enter?

§ 7. Our first knowledge of *matter* is derived from our *touch:* a consciousness of resistance in surrounding objects to the sense with which our bodies have been endowed, impresses us with a conviction of their *substance*, of their *extension*, of their *impenetrability*, of their power, that is, to exclude everything of the same kind from being in the same place. This tactile property is possessed by different parts of the skin in very different degrees; and some parts of the body, from their peculiar organization, are capable of much more delicate impressions from objects with which they may be placed in contact than others. With regard to extension, for instance, it appears, from the experiments of Weber, that the tips of the fingers or the tongue are capable of appreciating the distance between the points of a pair of compasses which are only one line apart; while the arm or the thigh would confound the two impressions together, even at the distance of thirty lines. Those whose touch has been educated by practice, can rule, by their feeling, fine linear divisions which are totally inappreciable to the most experienced eye.

Different degrees of resistance may even inform us of the different states in which matter exists: a touch will satisfy us that the parts of some bodies are immoveable among each other; that the particles of others are moveable with little resistance; while the passing breeze of air will convince us that matter exists in a form which yields to the slightest breath. A little reflection upon our sensations may thus establish a difference between *solid, liquid,* and *aeriform* matter. Experience, again, and the oft-repeated experiments, it may be said, of infancy, teach us to combine observations of touch with those of sight and hearing; and thus we learn to substitute the indications of one sense for those of another, and to judge of distant forms of matter.

With regard to the ultimate constitution of matter, we cannot hope to attain to a clearer conception than that which presented itself to the comprehensive, but humble mind of Newton; and that transcendent philosopher has thus imbodied the result of his patient investigations:

"It seems probable to me that GOD, in the beginning, formed MATTER in solid, massy, hard, impenetrable, moveable particles, of such sizes and figures, and with such other properties, and in such proportion to space, as most conduced to the end for which he formed them; and that those primitive particles, being solids, are incomparably harder than any porous bodies compounded of them; even so very hard as never to wear or break in pieces; no ordinary power being able to divide what GOD himself made one in the first creation."

§ 8. It is, however, no less necessary to test the accuracy of our notions derived from common observation and the first impression of our senses, than to guard against the careless adoption of ill-understood generalizations of the results of experiment in our after progress; and we must be particularly careful to correct the prejudices which are but too apt to infect the mind from this first fountain of our knowledge. With regard to the absolute hardness, for instance, of the ultimate atoms of all kinds of matter; from the smooth flowing of water, and the gentle breathing of the air, we derive a notion of softness which we can scarcely separate from the constitution of their ultimate particles; but if we take a portion of water in a glass tube, which has been carefully freed from air by boiling, and afterward hermetically sealed, we shall find, upon agitating it, that the particles strike one er with a ringing sound, quite undistinguish- rom that derived from the collision of metals. a little apparatus is commonly made, and by the name of the *water-hammer.* So with l to aeriform matter; a mixture of airs may nfined in a mere film of water, which, explo- t a lighted taper, will allow the particles of the phere to rush together so suddenly as to pro- a loud report, the result of the collision of rm atoms.

in, Newton has drawn a marked distinction en the solidity of "primitive particles" and f the bodies compounded of them, asserting he latter are *porous:* and yet we seem but to ing fair credit to the testimony of our senses, ieving that the particles of a solid metal must close contact. A little reflection again may t this prejudice. Many metals may have lensity increased, *i. e.*, their particles approx- d, by mere hammering or pressure; but to this is a limit: all solids may have their particles ximated by cold, and to this no limit has been scertained. Particles which admit of such r approach to each other cannot, of course, be se contact; a mass, or an assemblage of such, be porous.

If we are liable to such errors of judgment regard to matters of direct observation, how il ought we to be, and how diffident, in im- ng notions of things which are wholly beyond ognizance of our senses; as of the sizes, , or weights of the "primitive particles" or of matter. We can carry the palpable di- of some substances to an almost inconceiva- tent, but we have no reason to suppose that iereby even approximate to their ultimate resolution.

gallon of water weighs 70,000 grains; one of a grain of green vitriol does not contain quite one fiftieth part of a grain of iron; if we dissolve this quantity of the salt in the water, its diffusion throughout its whole mass may be rendered perfectly visible by the addition of a little tincture of the gallnut; *i. e.*, it may be proved to the eye that each grain of water contains the seventy thousandth part of the fiftieth of a grain of iron; a quantity far too minute to be ascertained by the most delicate instruments, and of which the imagination itself cannot possibly frame an accurate conception: and yet we dare not assert that this inconceivably minute quantity bears any assignable proportion to the weight of a primitive particle.

§ 10. But to proceed: we are familiar with matter in two states, viz., at rest, or undergoing a change of position in space; but no particle of matter, nor assemblage, nor compound of particles of matter, possesses within itself a power of changing its existing state of motion or rest; a passive quality which is generally designated by the *term* INERTIA. This term, however, appears to have been not very happily chosen, inasmuch as it might be taken to designate inactivity with regard to other bodies, which, if we were to admit, we should deny that inherent activity by which it is probable that every particle of matter is capable of acting upon every other particle in the universe.

When we are told that a body at rest would for ever remain quiescent unless it were to receive an impulse from some extraneous power, the mind at once assents to the proposition; it seems to agree with the results of our experience; the bodies which surround us move not until some power from without sets them in motion: but it requires some reflection in those who, for the first time, consider the subject, to perceive that bodies in motion would for ever continue to move unless they were stopped by some exterior power. Common and careless observation seems to contradict this part of the proposition: we know of no motion on the surface of the earth but what comes to an end, unless extraneous power be applied not only to produce, but to maintain it. This prejudice will, however, be corrected by the observation, that all such moving bodies meet with resistance from counteracting forces, and that the heavenly bodies, the only examples with which we are acquainted of unresisted motion, continue constant in their courses. Moreover, we are not without familiar instances of this tendency to a persistence in a state of motion. If we suddenly check motion in an open vessel filled with a liquid, the rigidity of all the parts of the solid mass brings them simultaneously to a state of rest; but the mobility of the liquid particles of the combination allows of their continuing in motion in their original direction, and the liquid is spilled. The careless setting down of a pail of water or of a cup of tea, may thus, with proper reflection, illustrate an important principle.

§ 11. Now every particle of matter which we see around us is under the influence of several FORCES, exerted upon it both by distant and adjacent particles, and upon which it acts in return; for the *action* of one body upon another is always accompanied by a *reaction* of the latter upon the former of the same intensity in the opposite direction. To these forces the motions which we observe in some bodies are owing, and upon their balance the apparent state of rest in others is dependant: it is therefore of the first importance that we should form as accurate a notion as possible of the meaning of the general term FORCE. The following analysis of the subject, by Sir John Herschel, clearly refers the origin of the idea to the consciousness of each individual.*

"We are conscious of a power to move our [illegible]

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* HERSCHEL'S Discourse, § [illegible]

limbs, and, by their interventio
this effect is the result of a cert
cess which we are aware of, b
force; and even when such ex
visible effect (as when we press
lently together, so as just to o
effort), we still perceive, by th
haustion, and by the impossibili
the effort long, that something i
us, of which the mind is the agent
determining cause." In the case
by the right hand, and met by an
the left, the two, acting in opposite
ly neutralize each other, and no n
effect is *pressure;* they exactly bal
and may be said to be in *equilibri*
a similar power of generating f
mals by opposition to our own;
imate seat of it is in the muscles,
muscular or *animal force.* This f
municated to inanimate matter,
ject a stone from the hand; and
set in motion carries force with i
arresting it in its course. Thus,
at cricket, we feel a shock, and
hand might even be fractured by
not at first yield a little to its co
concentrated in the same mass
tion, as when a stone, which, wh
hand, will inflict a comparativel
continuously acted upon by the
intermedium of a sling, it will at
ed with an intensity of action cap
very violent effects. We thus lea
tion in matter, however produced,
indication of force.

Velocity of motion may, when
the same, be taken as a measure
(as force thus transferred to movi

ter is called), and by multiplying the mass of a body by the square of its velocity, we in all cases learn its *momentum*, or the quantity of force which it is capable of exerting upon other bodies opposed to it. The investigation of the laws of motion constitutes the province of DYNAMICS.

§ 12. This force, which we can exert and communicate at will, and which can be generated by all animal bodies, we may soon become sensible may be opposed by other forces appertaining to inanimate matter. For example: in lifting a lump of iron, or lead, or stone from the ground, we are conscious of the same kind of opposition and consequent exertion as when we violently press one hand against the other; and whatever opposes force must be force. If the force which we apply be greater than the opposing force, which we familiarly denominate *weight*, the mass is raised; but we may so adjust the two that they may be *in equilibrio*, and then no motion will be perceptible; but we shall feel its *pressure*, and, if the mass be considerable, we shall not long be able to maintain the balance, from exhaustion and fatigue, and the mass will fall to the ground.

Again, by pressing with the arm upon a strong spring, or in drawing a bow, we feel another opposing power, which we denominate ELASTICITY. At the first impression motion may be produced, because muscular force may have the advantage; but we shall soon become conscious of a gradually increasing opposition, which our utmost exertion will not be able to overcome; our highest degree of force will be balanced; fatigue on our part will put an end to the contest, and the elastic body will return to its former state. If the opposition be suddenly withdrawn, and the bow be allowed to act continuously in its return upon a body which is free to obey the impulse, the bolt or the arrow will have a projectile force communicated to it of considerable intensity, as in the case of the stone from the sling.

§ 13. The very same effect may be produced upon the spring or bow by the action of the weight as by the power of the arm; and if we were to place the mass of iron upon the former, or suspend it from the latter, the heavy body would be supported, and the elastic body would be bent. Weight may thus be opposed to elasticity, and at a certain point they will balance each other: at this point no motion or visible effect will be produced; but the two forces will not on this account cease to act any more than in the case of the opposite pressure of the two hands; they will exert pressure upon each other. Each of these forces having been separately estimated by our exertion and consciousness of muscular force when opposed to them, we cannot resist the direct evidence of our senses, that "matter is thus capable of exerting upon matter the same kind of effort as that which we appreciate from a mental impression."*

There are several varieties of such force, all of which may either *mediately* or *immediately* be referred to the standard of our own exertions. Some of these cause masses of matter to approach and others to recede from each other; the former are classed together under the name of ATTRACTION, the latter under that of REPULSION. The laws of these motions, and of the equilibrium of these forces, the intellect of man has been able to develop; but the origin of the forces themselves, though clearly perceived to be various, appears to be beyond comprehension, even when that origin is in his own will. We cannot, at least, refer them to any secondary cause, and we must be content to know that they are powers conferred upon matter by the will of the CREATOR, for the maintenance of the order of his creation. Thus much the intellect of a child can comprehend, and to nothing more did that of a Newton attain. The effort which we feel that a mass of iron makes to fall to the ground, is due to an attractive force between it and the earth, which we denominate GRAVITY, and is a universal power of nature; that which we feel the spring make to recover its first position when we press upon it with the hand, is due to the repulsive force of ELASTICITY, and is possessed in very different degrees by different kinds of matter.

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* HERSCHEL's Discourse.

Before we proceed to inquire into the laws which limit the action of these forces, it will be well to indicate certain other varieties of *repulsion* and *attraction*, which will come within the scope of our inquiry.

§ 14. It was observed by the ancients, and the fact is mentioned by Theophrastus, that when a piece of amber is rubbed, it acquires the property of attracting light bodies. The Greek term for amber being *electron*, the unknown cause of this phenomenon has been called ELECTRICITY. It was not till the commencement of the seventeenth century that the same property was found to be conferred, by friction, on various other bodies, as glass, sealing-wax, sulphur, &c.; and later still, that any two dissimilar substances, when rubbed together with proper precautions, are capable of exerting the same attracting force. Farther observation has shown, that after bodies have been thus attracted to the rubbed surface, they will be repelled from it by an equal but opposite force; and the *phenomena* will be presented to us in a striking light if we suspend a feather from a piece of silk, and approximate to it a tube of glass, which has been rubbed with a silk handkerchief; the feather will be attracted to the tube from a considerable distance, and, after attaching itself to it, will fly off, and cannot be made again to approach it. Both this attraction and

repulsion will overcome the force of grav
the feather, and by its opposition we can
the amount of either.

§ 15. Again : there is an ore of iron whic
mon in Sweden, which has received the
loadstone, from the property it possesses of
when freely suspended, to the polar star,
star, as it was formerly called ; it has bee
from remote antiquity to possess the pow
tracting small pieces of iron ; it is said
abounded in Magnesia, a province of Lydi
mentioned by Pliny under the name of
hence the property derived the name of MA
It is capable of being communicated to bar
by friction, which are also called *magnets*
take two bars so prepared, and balance one
upon a pivot, we may again have the opp
ces of attraction and repulsion exemplifi
this new source ; for upon approximating
of one magnet to a certain end of the othe
is free to rotate, they will approach each ot
considerable energy ; if the other end be p
to it, they will separate with equal velocit
attraction we can feel and estimate by the
force which we must exert to pull away a
iron which is under its influence. Artificial
as well as the loadstone, when freely su
take up a definite position with regard to
of the earth, or the extremities of any other
hence this property has been termed *polar*
forces which are conceived to act with equ
sity in opposite directions at the extremiti
axes or molecules of masses of matter, are
inated *polar forces*.

§ 16. The forces which we have thus de
may be distinguished as EXTERNAL FORCES,
act upon masses of matter at sensible di
there are others which act only upon its co

molecules, and at insensible distances, and may be called INTERNAL OR MOLECULAR FORCES.

§ 17. The first and most general of these is *homogeneous attraction* or *cohesion.* If we take two *masses* of lead, on which two perfectly smooth surfaces have been cut—a cloven bullet will answer the purposes of illustration—and bring these planes in contact, we shall find that they cohere or attract each other with a force which we can appreciate by a muscular effort to separate them: or by opposing to them the gravitation or weight of another body, for we may suspend a heavy substance to them without forcing them asunder. In the same way, two pieces of plate-glass cohere strongly together, when brought into contact, by their polished faces. It has often happened in manufactories of this article, that the plates, which, after receiving their last polish, are placed in cases where they are arranged like books in a bookcase, a little inclining upon each other, have been found to have contracted so strong a *cohesion* as not to be separable without a fracture; and sometimes three or four plates have thus become so incorporated as to bear working together, and cutting with a diamond like a single plate. Some specimens, which were selected from the manufacture of St. Gobin, were found to be thus united no less intimately than if they had been fused together; and when a violent degree of force was applied to make them slide from each other, the experimenter was surprised to find that the substance of the glass was actually torn, so that the surface of one was actually covered with large flakes detached from the substance of the other.

Another example of this force is afforded by the running together of two globules of mercury or two drops of water; the moment they appear to touch each other, they coalesce and become one. One of the most striking illustrations of homogeneous attraction is afforded by sifting some finely powdered resin upon a plate, and carefully ing a few drops of water upon it; each will assume an almost perfect globular for the equal action of this force, in all directi the centre, in obedience to which the par each mass are free to move; these sma may be made to roll about in all directions, l shot, by inclining the plate. When made g touch each other, they still continue sepa liquid particles being defended from actual by the light dust with which they are po but when, by greater violence, this is di they immediately run together.

This is the force which connects the par bodies together in the solid form with gr less energy, and which still prevails in though reduced to a less amount by an o force which we must presently indicate. V seen from our experimental illustration sho ity or muscular force may be made to act i sition to it, and the two may be combined to degree of intensity by the continuous act instance, of the sledge-hammer, that the c of the hardest solid may be obliged to yield.

And here it may be remarked, that *time* is portant element in the action of force. V mass of matter moving with a certain *mo* strikes against a substance whose cohesion ficient to resist the force which it conveys, t ture of the latter is the consequence, and t mentum of the former may be destroyed; greater velocity be given to the mass, it m through the opposing substance with little co tive injury, and still continue to move. leaden bullet projected from the hand may ish a plate of glass, while the same bullet i from a gun will pass through the plate and it with a small hole, without destroying the sion in any other part. In the practice of ar where it is required to batter down walls or the sides of a ship, the charge of gunpowder is so regulated as that the projectile may not be carried through the object aimed at; as in that case the time of its passage is not sufficient for the transfer of the force from the moving body.

§ 18. Elasticity also may be made to act against cohesion; and a most beautiful instance of the *equilibrium* of these two forces is presented to us in the common schoolboy's plaything called a Rupert's drop. This is a drop of glass suddenly solidified by dropping it into water; its cohesion is very considerable, as we may ascertain by the force which would be required to crush it; it will bear the pressure of half a hundred weight without injury. Glass is also a body endued with a high degree of elasticity, which is greatly increased by heat. When the exterior molecules are suddenly cooled they contract, and violently compress the still heated interior particles. That these retain their state of tension, and strive energetically to recover from it, even after they are cool, is proved experimentally. If we grasp the drop in one hand, and with the other break off the point or merely scratch the surface, we diminish the force of cohesion, and the elasticity assumes the ascendency, breaking the mass to an almost impalpable powder, and giving a violent shock to the hand which grasps it. By holding it under water in a stout glass bottle or other vessel, the effect is rendered still more striking; for, upon scratching the surface with a file, not only is the drop, but the containing vessel, shivered into a thousand fragments.

§ 19. But the real, and, but for one remarkable exception, *universal* antagonist of cohesion, is the repulsive force of HEAT: and of the meaning, again, of this term, our consciousness will afford the best explanation. The sensations of the most ignorant teach them to apply a meaning to the terms *hot* and *cold*, which the most philosophic definition would not at all elucidate. Common experience proves to us that the unknown cause of these sensations is an agent of the most powerful and active kind: we find it continually employed both in the processes of nature and the arts; we recognise it as destroying some substances, melting others, rendering others luminous, and converting others into vapour. The hidden cause of all these effects we term *heat*, as well as the sensations which it produces upon our organs. Our ignorance occasions this confusion of language, and we only attempt to disguise that ignorance when we substitute the term *caloric* for the mysterious cause, and confine the term heat to the sensation produced.

§ 20. When we take a half flaccid bladder, and expose it to any of the common sources of heat, as by holding it before the fire or pouring hot water upon it, we invariably communicate a repulsive force to the air which it contains, causing the particles to recede from each other, and distending the bladder to a degree which, if properly confined, will cause it to burst with a loud report. Here again we may *feel* the force which causes the aerial molecules to repel each other. Common experience has also taught us that the application of heat will quietly subdue the cohesion which binds together the atoms of the most solid metal, and which the most intense mechanical force can only very partially effect; and hence, again, we judge of the energy of the active cause.

Such are the forces of *homogenous attraction and repulsion*; antagonist powers which act upon the constituent particles of the same kinds of matter; matter that is of the same sensible properties.

§ 21. Referring back to our first acquaintance with matter, we have not only been assured of its existence, of its substantiality, of its impenetrability, of its solidity, of its fluidity by our touch, but our other senses have discovered to us different kinds of matter; matter of different sensible properties. Our taste has informed us of sapid and insipid, of acid and sweet, and bitter and saline matter; our organs of smell, of odorous and inodorous bodies; our sight, of blue and green, and black and white, transparent and opaque. It is in the reciprocal action of bodies of such different essences that we trace the existence of our next active force. If we simply dip a piece of metal or glass into water, and withdraw it, we shall have an illustration of it in the wetting of the solid; a portion of the liquid will adhere to it: we can estimate the amount of the force by the weight of the water which may be raised under its influence. If we repeat the experiments before referred to, of placing a few drops of water upon a fine dust, substituting powdered flint glass for resin, we shall be able to contrast this force of *heterogeneous adhesion* with that of *homogeneous cohesion;* in the former case the drops of water assumed a spherical form, under the influence of the last power; in the latter case *heterogenetus adhesion* will overcome *homogeneous cohesion;* the powdered glass will be wetted, and the water will be absorbed.

§ 22. The last force which it will be necessary to specify, to complete this general view of the forces, is CHYMICAL AFFINITY, the highest degree of heterogeneous attraction. The action of this marvellous power between the ultimate particles of different kinds of matter, constitutes matter of distinct qualities; matter differing in essence from any of its ingredients; matter possessing no sensible property in common with its constituent elements but that of their gravity combined. An inquiry into the laws and results of its action constitutes the chymist's peculiar province.

§ 23. These illustrations may serve the useful purpose of fixing upon the minds of beginners in science some definite notions of the nature of the forces which principally concur to the production of chymical phenomena; the particular laws of their several actions, as far as they are conducive to this result, it is the object of the following pages to examine and illustrate; and for this purpose we will take them nearly in the order in which they have already been notified; and first, with regard to

GRAVITY.

§ 24. The *attraction of gravitation* is exerted between masses of matter at a distance from each other; it is that sublime power which the astronomer contemplates as extending between all the bodies of the solar system; binding the planets in their orbits, and reaching through space to countless other systems, at distances of which the mind of man strives in vain to form an adequate conception. With this stupendous and all-pervading force the chymist has little concern, except as acting at the surface of the earth, and conferring the property which we call *weight*.

It may be exemplified not only by the fall of a body to the earth, but by the approach towards each other of masses of matter which are free to obey the mutual impulse. Thus, pieces of wood, upon the surface of water, are attracted towards each other or the sides of the containing vessel; and the wrecks of ships are frequently found aggregated together upon the surface of the ocean.

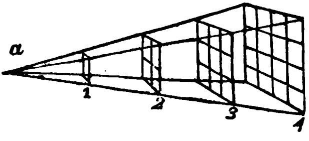
A *plummet*, or weight suspended to a string, is commonly employed to indicate a line directed immediately to the centre of the earth, and which is called a perpendicular. This is the direction of gravitation, which acts in straight lines, when undisturbed, at the surface of the globe. The same plummet, when suspended by the side of the abrupt precipice of a mountain, has been experimentally found to deviate from this perpendicular, having been drawn aside a minute, but measurable quantity, by the gravity of the mass in whose vicinity it has been placed.

In common language, we say that a stone or other heavy body falls to the earth: but the influence is reciprocal; the earth is attracted by the stone as the stone is by the earth. The action is directly proportionate to the quantity of matter which each mass contains, and this is the first law of gravity. The quantity of matter in the stone bearing no assignable proportion to the mass of the earth, its influence, though certain, is inappreciable.

§ 25. Here again it may be necessary to guard against a prejudice derived from careless observation and an inaccurate language: lead is proverbially said to be heavy, and a feather to be light; and when a mass of lead and a feather are suffered to fall together to the ground from a height (when abandoned, that is, at the same moment, to the action of gravity), the former reaches the bottom sooner than the latter, gravity appearing to act with greater energy upon one than the other. But if the experiment be made in a space void of other matter, the action upon both will be found to be equal; they will both fall together, and we shall learn that the retardation of the feather, in the first instance, was owing to the large surface which it presented to the resistance of the air. *In vacuo* the smallest particle of matter and the largest mass fall through equal spaces in equal times. *Gravity*, in short, is the power of transmitting to every particle of matter a certain velocity absolutely independent of the number of material particles: *weight* is measured by the effort which must be used to prevent a given mass, or accumulation of particles, from obeying the law of gravity; weight, therefore, depends upon the mass: gravity has no dependance at all upon it.

§ 26. The intensity of the force of gravity is measured by the velocity of a body moving unresisted under its influence, and is such that in this latitude a body falls, in the first second of time, 16.095 feet, or about 16 feet and one inch.

§ 27. The second law of gravity is, that bodies attract one another in inverse proportion to the squares of the distances of their centres, to which their action may be referred. Now this is the law which regulates the action of all central forces; of all forces, that is, which emanate from a centre, and spread themselves around that centre; and its generality renders it particularly desirable that we should form an accurate notion of its reason. We can best explain it, perhaps, by reference to light. Common experience informs us that the intensity of light decreases with its distance; and in what proportion, a little consideration will enable us to determine. A lighted taper radiates its light in all directions alike; if we imagine such a taper placed in the centre of an opaque globe four feet in diameter, its light will all be dispersed over, and arrested by, the surface of that globe, which will be illuminated with a certain degree of intensity. If we now imagine it removed to the centre of another sphere six feet in diameter, the same light will be spread over the larger surface, which will, of course, be illuminated in a less degree. The distance of the light from the surface of the first sphere would be its radius, or two feet; from the surface of the second, three feet; but the diminutions of the light would not be directly as 2 to 3, or as the mere distance, but as the squares of 2 and 3, or 4 to 9; for it can be geometrically demonstrated that the surfaces of spheres, or any similar sections of spheres, are as the squares of their radii;(1) and it is clear



(1) The principle may be illustrated by experiment in the following way: If, in the annexed diagram, 1 represent a board of a foot square, placed at a certain distance from a light at *a*, it

that in each case the light is spread over the whole surfaces, and, consequently, diluted in proportion to their surfaces. In the same manner and after the same law, the action of gravity is diluted, if the expression be allowable, upon distant masses.

§ 28. If a gravitating body be freely suspended by a string or rod from a fixed point, it will hang in a vertical position; but if it be moved from that position by a force laterally directed, it will rise in the arc of a circle, of which the point of suspension will be the centre, under the joint action of the moving force and the tension, or cohesion, of the rod or string. When it has reached the point at which its moving force is destroyed by the counteracting forces of gravitation and cohesion, it will immediately begin to descend under the force of gravitation in the same arc; and when it reaches the vertical position, it will have acquired a *momentum* which would tend to carry it forward in a horizontal direction; the tension of the string will, however, cause it still to move in the circle of which the point of suspension is the centre, and it will, after passing the vertical line, rise through a similar arc on the opposite side, until its velocity is destroyed, which, if no other forces than gravity and its antagonist, cohesion, were to act, would be when it reached a height equal to that from whence it first fell: from this it will again descend, and, passing the vertical, rise to the first height; and it would thus continue to oscillate for ever but for counteracting forces. The oscillations of an inva-

will just shadow a board of two feet square, 2, at double the distance; of a board of three feet square, 3, at three times the distance; or one of four feet square, 4, at four times the distance; that is to say, the light which is concentrated upon the first board would be diffused over four times the space, if suffered to fall upon the second; or over nine times the space, upon the third; or sixteen times upon the fourth. The boards may be considered (without any appreciable error) as similar segments of spheres, of the radii of their several distances.

riable *pendulum*, as such an apparatus is called, are sensibly performed in equal times, or are *isochronous*, even when the arc gradually diminishes from retarding forces.

The length of a pendulum vibrating seconds in the latitude of New-York (40° 42′ 43″ N.), *in vacuo*, at the level of the sea, has been accurately determined to be 39.102 inches.

The force of gravity, which, on account of the figure of the earth, varies slightly in intensity from the poles to the equator, may be determined for different places by the velocity of a standard pendulum, it being directly proportional to the squares of the number of vibrations in equal times: or as the lengths of pendulums are inversely proportionate to the square of the number of their vibrations in equal times, the force of gravity may be determined for any place by measuring the length of the pendulum which beats seconds at that place.

§ 29. *Momentum* may be accumulated to an enormous degree in very large masses thus suspended, by forces which, at their first application, appear to be totally inadequate to move them. By making repeated impulses coincide in time and direction with the first minute *oscillations*, the arc will gradually increase until a great degree of velocity is produced; and the force which is thus stored up is capable of producing a corresponding concentrated effect.

§ 30. According to the first law of gravity, the force with which the earth acts upon any body at its surface is in direct proportion to the quantity of matter which it contains; hence the measure of the force becomes the criterion of quantity, and the weight of a body is the exact amount of force, expressed with relation to some known standard, which is just sufficient to prevent that body falling to the ground. The commonest mode of ascertaining this is to oppose the known effect of the gravity of certain pieces of metal which have been compared with some conventional standard with the greatest possible exactness, to the unknown gravity of the substance whose weight or quantity of matter has to be determined. A pound is a mass of matter which has been thus adjusted; and the common business of life has rendered most men familiar with the multiples and sub-multiples of this weight, and the denominations of tuns, hundred weights, ounces, grains, &c., which have been conferred on them. The standard liquid measure of the State of New-York is the gallon, and the weight of pure water which it contains is 8 lbs. The standard of dry measure is also called the gallon, and contains 10 lbs. of pure water; the bushel, in consequence, holds 80 lbs. The method of comparison, by means of the balance, is also well known.

§ 31. The balance consists essentially of a uniform inflexible lever, delicately supported at its centre of gravity on a fine knife edge, and carrying scalepans freely suspended from points in the same horizontal line with the centre of gravity. If the weights or quantities of matter in each be equal, the one will counterbalance the other, and the beam will remain horizontal; if not, the heavier will preponderate. Lightness of construction and freedom of motion are secured by many ingenious contrivances, upon which it would be foreign to our present purpose to dwell. A good balance will indicate by its turn 1-5000th or 1-6000th of the weight which it is designed to carry, and will freely move with the difference of 1-1000th of a grain.

§ 32. Equality in the length of the arms of the lever is, of course, the most important consideration in the construction of the balance; but when there may be any reason to doubt this essential point, it is well to know that any error may be avoided by the method of *double weighing*. This consists in placing the object whose weight is to be ascertained in one scalepan, and exactly counterbalancing it in the other, not with the weights, but with sand or shot, or any other indifferent substance. The substance is then removed, and the weights applied in the same pan, till the counterpoise is balanced. By this contrivance the unknown quantity of matter is compared with the known, under exactly equal circumstances, and the result is independent of almost every source of error which can affect the comparison of one object with another.

§ 33. The second law of gravity has little to do with the determination of weight, and for this purpose may safely be disregarded; for any variation of the distance from the centre of the earth, at which we may carry on our operations, is so small, with regard to the whole, as to be perfectly insignificant, although not inappreciable to the refinements of modern science. The mean radius of the earth, or the distance from the centre to the surface, is about 3941 miles; and supposing that we had to determine the weight of an object on the summit of a mountain one mile in height, the force of gravity would be decreased in the ratio $3942^2 : 3941^2$, which would make a difference of about one ounce in a tun weight. This difference would not, of course, be apparent in the usual manner of weighing by means of the balance; for the decrease of gravity would affect both the weight and the object to be weighed in the same degree; but it might be measured by the opposition of another force, as that of elasticity. A spring which would be bent to a certain degree by a tun weight at the surface of the earth, would require a tun weight and one ounce to bend it to the same amount on the summit of the mountain.

§ 34. Every substance in nature, occupying a given space, is found to have, under the same circumstances, a weight *specific* or peculiar to itself;

or, in other words, the same volume of different kinds of matter contains different quantities of matter. The comparative weights of equal bulks of different bodies are called *specific gravities*. This is a very important distinctive property of matter, and one to which the chymist has perpetual occasion to refer. In comparing specific gravities it has been found convenient to refer them to a fixed standard, and water has been generally adopted for this purpose, as being easily procurable in most times and places.

§ 35. The mode of taking the specific gravity of a liquid is very simple and easy of execution. A small stoppered flask is prepared to contain exactly 1000 grains of pure water; this is filled with the liquid, and placed upon the balance; in the opposite pan is placed the counterpoise of the bottle when filled with water, and, when heavier than water, so much weight as will adjust the beam. If the liquid be lighter than water, the weight must be placed in the same pan with the bottle.

In the first case, the weight in grains added to 1000, and in the second case deducted from 1000, will give the specific gravity sought. Thus the same bottle which held 1000 grains of water was found to contain only 839 grains of spirits of wine; and, taking water as 1, the specific gravity of the spirit is said to be 0.839.

§ 36. It would be impossible thus directly to compare a given volume of any solid body with an equal volume of water; were there no other obstacle, it would require a nicety of measuration and workmanship which would be quite unattainable. But the same end may be obtained with perfect accuracy by means which are easily applied. The rule is to weigh the solid in air and afterward in water, and, having found the deficiency of the latter weight, to divide it by the former, and the quotient will be the required specific gravity. Now there is nothing more injurious to the progress of a student in any science than the acquirement of such rules by rote, without a thorough comprehension of the principles upon which they are founded; they may thus be rendered available for mere practical purposes, but they are utterly useless as steps in his advancement. For instance, how many thousand persons are there who can (to make use of a common expression) work the rule of three, without in the least understanding the doctrine of proportion upon which it is founded? With less trouble than it takes them to learn and recover the rule, which they are in constant danger of forgetting, they might attain to a knowledge of its principles, which would not only be of general application, but a help to farther improvement. A little consideration will be sufficient to render the principles of the above process perfectly clear. When a solid is wholly immersed in water, it obviously displaces a bulk of that liquid exactly equal to its own, which bulk was supported in its place by a pressure from the surrounding particles equivalent to its own gravity: this may be easily proved by the familiar illustration of a bucket in a well. When the full bucket is wholly immersed in the water, it requires scarcely any effort to draw it to the surface; but the moment it rises above the water, the weight of the water is felt, being no longer supported by the surrounding liquid. In the process, therefore, of taking specific gravities, the solid immersed must also be supported by the surrounding water with a force exactly equal to the weight of the water which it has displaced, and thus the difference of its weight in water from that of its weight in air must be the weight of an equal bulk of water. The direct comparison of the substance with water having been thus effected, a number bearing the same ratio to unity is easily found by the rule of proportion, and this will be the specific gravity.

An example may, perhaps, render this more clear. A lump of glass is found to weigh in air 577 grains; it is delicately suspended by a horsehair from the bottom of the scalepan, and immersed in a vessel of pure water, it is found to weigh 399.4 grains; the loss, therefore, or the weight of an equal bulk of water, is 177.6 grains; then 177.6 : 1 : : 577 : 3.2; the working of which sum resolves itself into the division of the third term by the first, or of the weight in air by the weight in water, according to the rule. The quotient 3.2 being the specific gravity of the glass.

Solid bodies lighter than water, such as cork, may be weighed by attaching to them a mass of metal or glass previously balanced in water for that purpose, which may cause them to sink, and then proceeding with the combined mass as before.

§ 37. The same principles may be applied to ascertain the specific gravity of liquids instead of the specific-gravity bottle; for as a bulb of glass immersed in water is buoyed up by a force equivalent to the weight of an equal bulk of water, so, when immersed in any other liquid, it will be supported by a pressure equal to the weight of a similar bulk of that liquid. Thus the mass of glass which lost 177.6 grains by immersion in water, was found to lose only 149 grains by being plunged into the spirits of wine, and their two amounts are consequently the weights of equal bulks of water and spirit; therefore 177.6 : 1 : : 149 : 0.839, the specific gravity of the spirit.

§ 38. It is upon the same principle that the specific gravities of liquids, which do not differ much from one another, may be determined by the *hydrometer*. This instrument consists of a hollow ball of glass or metal, with a weight below it and a slender stem above, divided into a certain number of degrees by marks; in pure water it is adjusted to float to a particular mark; that part of the stem which is out of the liquid acts as a weight to keep

But the force with which a body is attracted to the earth, and, consequently, the quantity of matter which it contains, may be measured by opposing to it other forces than that of gravity. We can even roughly judge of different weights by the different degrees of muscular exertion necessary to support them; and we have already had occasion to refer to a method of estimating them by the compression of a spring. This observation will naturally lead us to the consideration of our next force; namely,

ELASTICITY.

§ 40. The immediate resistance of a body to compression or extension, is properly called its elasticity. It has been exemplified by the sensible effort of a compressed spring and a bent bow to recover from their forced state of flexure. It is directly proportionate in perfectly elastic bodies to the compressing force; and this is the law of its action. If a bow be drawn to a certain extent by a seven-pounds weight, it will be drawn to double that extent by fourteen pounds; and upon this principle various spring-balances have been contrived.

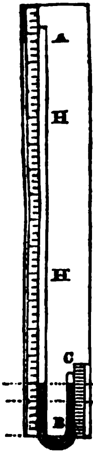
The kind of elasticity to which we have hitherto referred arises from a force longitudinally applied, and a partial displacement of the particles of a solid in length, and is denominated *flexure:* a second kind consists in the lateral displacement of the opposite parts of a solid, in opposite directions, the central parts only remaining in their natural state, and is called *torsion* or *twisting*. Elasticity, thus elicited, may be very accurately measured by the angular displacement; the angle of torsion being exactly proportionate to the degree of elasticity. Balances of the greatest delicacy have been constructed upon this principle for the estimation of minute degrees of force.

But solid bodies are only more or less elastic within certain limits; the operation of forces beyond these limits first produces a permanent alteration or change of figure, which is called *setting*, and afterward *fracture*. The most perfect examples of elasticity are afforded by aeriform bodies; and the atmosphere which surrounds us furnishes a beautiful illustration of the equilibrium of this force and gravity, a correct understanding of which is of the greatest importance.

§ 41. With regard to matter in the aeriform state, common experience is by no means sufficient, as with solids and liquids, to teach us how to collect, confine, or weigh it; and it was not, till the time of Galileo (or early in the seventeenth century), proved that the air had a definite weight and pressure; and it was some time after this that Dr. Priestley contrived the simple means which are still in use for experimenting with such fluids. Aristotle, indeed, appears to have happily guessed the truth; and Plutarch informs us that he assigned the gravity of air to be between that of fire and earth; but the surmise appears to have led to no particular consequences, and to have been forgotten.

§ 42. If we take a bell-glass, and press it with its mouth downward into a deep vessel of water, we find a strong resistance to its descent, which arises from the body of air confined beneath it; as we press upon it more and more, we feel a stronger and stronger opposition or repulsive force; the water rises farther into the interior, and the air occupies a less space; as we withdraw the pressure, it returns to its former bulk, and totally displaces the water. Hence we may learn that the air is elastic, like the spring to which we have just referred; and we can roughly estimate by our feeling that its elasticity increases in proportion to the force with which it is compressed. We learn, likewise, from the same simple experiment, that the volume decreases with the increase of pressure. The law of its elasticity was originally developed by Boyle; but Mariotte more accurately determined, by experiment, that the volume of air was always inversely as the pressure.(3) Elastic fluids of this nature always occupy the whole of any vessel in which they may be contained, whatever their quantity of matter may be, as determined by their weight; liquids or fluids devoid of this power of elasticity, in vessels which they do not fill, always present a level surface, *i. e.*, a surface parallel to the general surface of the globe. This is determined by gravity, the law of which they are free to obey, unopposed by any counteracting force; the surface of an elastic fluid is always coincident with that of the containing vessel in which it is confined.

§ 43. If we take a strong tube or barrel of metal or glass, close at one end, and closely fitted at the other with a piston or moveable plug of leather, which will not allow of the passage of air at its sides, on pressing it downward we shall find the same kind of increasing resistance from the included air, as in the case of the bell-glass under water. This elastic force may be made to perform mechanical work; and if the piston be perforated, and the per-



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(3) This figure represents the form of Mariotte's experiment. A B is a glass tube, turned up, and closed at the end, C; it is divided and graduated into equal parts; mercury is poured into it, so as to occupy the lower part of the tube to the first horizontal line, and a portion of air is enclosed at C of the ordinary elasticity, which it will be hereafter seen is equal to the pressure of about thirty inches of mercury. If more mercury be now poured into the longer leg, so that it may stand at thirty inches above the level of the mercury in the shorter leg, it will press with its whole weight upon the included air, which will then be found to occupy only half its former space. If, in like manner, the column of mercury be increased to twice this length, the pressure upon the included air will be tripled, and the space occupied by it will be reduced to one third, &c.

foration be covered with a valve, or little door, opening upward, as we press it down the elasticity will raise the valve and allow it to escape, and the piston will freely descend. If we attempt again to draw the piston up, we shall feel a strong opposition in the contrary direction. As the piston rises, an empty space is left between it and the bottom of the barrel; for the exterior air, in attempting to pass in, by its elastic force firmly closes the valve. If by strong muscular force we succeed in drawing the piston up, upon discontinuing the effort it will be forced down again to the bottom by the exterior pressure. Let us suppose now the bottom of the barrel to be fitted with the same kind of valve as the piston; as the latter ascends, the elasticity of the portion of air included in any vessel with which it may be connected will raise the valve, and the air will flow into the barrel: when the piston is again forced down, this valve will be closed by the force above it, and the included air will again pass off through the piston-valve, and we can repeat this operation, gradually withdrawing barrelful after barrelful of air from any vessel till the residual air becomes so reduced as not to have elastic force enough to raise the valve. Two such barrels so fitted with pistons, with a mechanical apparatus for alternately raising and depressing them, constitute the essential parts of the airpump.(4)

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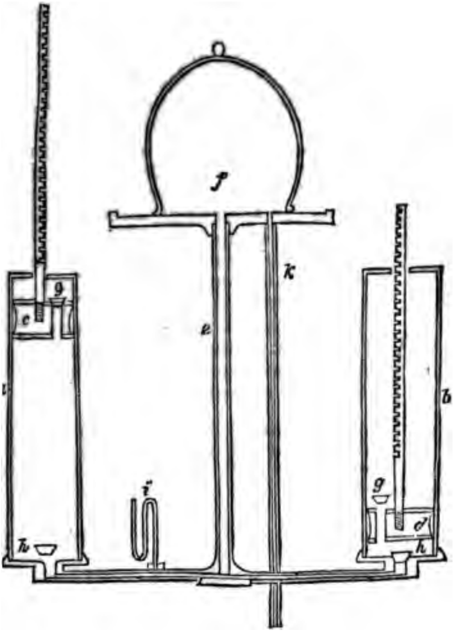
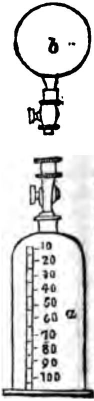
(4) *a* and *b* in the opposite figure represent the cylinders, in which the pistons, *c* and *d*, are accurately fitted; at the bottoms of the cylinder are the valves *h*, *h*, opening upward; and in each piston is a valve *g*, *g*, also opening upward; the bottoms of the cylinder are connected by a tube, *e*, with the pump-plate, upon which stands the bell-glass *f*; in the cylinder *a*, the piston is represented in the act of ascending, when the valve *g* is closed, and a vacuum would be formed beneath the piston but for the opening of the valve *h*, by the elasticity of the air in the receiver. In the cylinder *b*, the piston is in the act of descending when the valve *h* is closed, and the valve *g* open, by which all the air in the cylinder is forced out; and in this man-

§ 44. Now if we take a thin glass globe or flask, ted with a stopcock, we may, by these means, haust it of the greatest part of the air which contains, and equipoise it upon the balance. pon opening the stopcock, air will rush into the mpty vessel, and it will preponderate; and it will quire a considerable weight in the opposite scale restore the equilibrium. To ascertain the exact

a portion of the air is withdrawn from the receiver *f*, at y stroke of the pump.



weight of any given volume of air, it will be necessary to measure it, and this we cannot do by measuring the capacity of the globe, for the best air-pump will always have a residual quantity after exhaustion; but by connecting the exhausted vessel with an accurately graduated jar,(5) standing upon the water-bath, the air may be able to enter from the latter, and the rise of the water into the jar will indicate the exact quantity which has been thus abstracted. By careful experiments, conducted upon this principle, it has been found that 100 cubic inches of atmospheric air, under standard circumstances, to which we must hereafter advert more particularly, weigh 31 grains, or 815 times less than an equal bulk of water. We shall find that there are many different kinds of aeriform matter, differing very greatly in their specific gravities; this is the mode by which they may be ascertained, and atmospheric air is the standard to which they are all referred, just as the specific gravities of solids and liquids are compared with water.



In the following table are included the weight of 100 cubic inches of the lightest and heaviest known forms of matter: of the same quantity of atmospheric air; and of water in its three physical states. The specific gravity of each, compared with air and water, is also shown.

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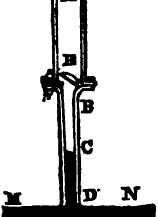
(5) *a* represents the air-jar, graduated into cubic inches and parts of a cubic inch; *b* the glass balloon; each is fitted with a stopcock and conecting-piece.

TABLE I.—*Of Specific Gravities.*

	Cubic Inches.	Weights. Grains.	Specific Gravity, Air 1.	Specific Gravity, Water 1.
Hydrogen .	100	2.138	0.0694	0.0000846
Air . .	100	31.000	1.0000	0.0012277
Steam .	100	19.220	0.6240	0.0007611
Ice . .	100	23735.000	765.0000	0.9400000
Water .	100	25250.090	814.0000	1.0000000
Platinum .	100	542875.000	17512.0000	21.5000000

§ 45. The weight or pressure of the atmosphere was first, however, demonstrated in a different way by a celebrated Italian philosopher, named Torricelli, in the year 1643. His attention was drawn to the subject by the attempt of a well-digger, at Florence, to raise water by a sucking-pump to a height exceeding 33 feet. The rise of water in a tube by these means had, up to that time, been ascribed by philosophers (who, as it is to be feared sometimes now happens, disguised their ignorance under the cloak of indefinite and specious expressions) to *Nature's abhorrence of a vacuum.* The well-digger failed in his enterprise, and applied to Torricelli for advice; who, seeing the absurdity of the conclusion that nature only abhorred a vacuum to the extent of 33 feet, suspected that the cause of the ascent of water in the pump-pipe might be the pressure of the atmosphere; and that a column of water about the height mentioned was sufficient to equipoise the air.(6)

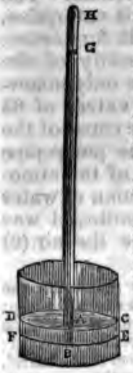


(6) The annexed figure represents the construction of the common sucking-pump; A B is the barrel fitted with a piston, in which is a valve at A, opening upward; another valve E, at the bottom of the barrel, also opening upward, closes the communication with the pipe, B D, which descends

He concluded that, if this were the case, support a shorter column of any dens he immediately had recourse to experi firm his conjecture. He filled a glas feet long, and closed at one end, with and inverted it in a basin of the same flu diately sank about six inches from th tube; proving that the pressure of the which could support a column of wate feet in height, could only support a col cury of 30 inches, the height of the co in exact proportion to the specific gra two liquids, or as 13 1-2 to 1.(7)

§ 46. Thus was invented that useful the *barometer;* for a tube filled with tions wholly to exclude the air, and ac justed to a scale for the purpose of m exact height of the column from the su mercury in the cistern, constitutes th part of this simple but highly ingen

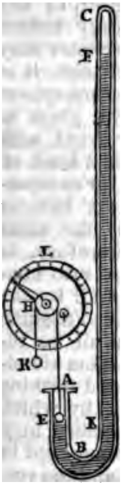
below the level of the water, M N. As the piston vacuum is formed beneath it, a elasticity of the exterior atmos upon the water M N, forces it the pipe from D to C. The des ton closes the valve E, forces ou tion of the air through the valve return the valve E again opens, is forced past it into the barrel. of the pump drives the water A also, and lifts it into the reser which it flows through the aper



(7) H B represents a tube, whic filled with mercury and closed has been carefully inverted bene D C, of the mercury in the glass Upon removal of the finger from has fallen in the tube from H to of mercury, A G, being the exa the elasticity of the atmosphere the experiment

vance.(8) In confirmation of the principles upon which it had been constructed, it was soon observed that, upon ascending a hill, the quicksilver fell in the tube, obviously because the column of air was shortened which supported it. This observation was, not long after, applied to the measurement of heights.

The gravity and elasticity of the atmosphere re-act upon one another in such a way that the space which the same absolute weight of air occupies at different heights must be the measure of both. If we suppose it divided into strata of equal thickness from the top, the first stratum will press downward by the whole of its own weight, but by nothing more; the second will press downward by its own weight, and will be compressed by the weight of the first in addition; a third will have to support its own weight and the weight of the two preceding; a fourth will be compressed by three, and so on, each stratum being compressed by the whole thickness of the one above it. Thus the pressure at different heights will be inversely as the squares of the distances from the surface of the earth, and will be measured by corresponding diminished heights of the column of mercury in the barom-



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(8) In this figure is represented the mode by which the fluctuations of the height of the mercurial column, F B, are indicated by the index upon the dial-plate H L, in the common wheel-barometer; a glass weight E, attached to a thread passing round a pulley, to which the index is fixed at B, and nearly counterpoised at K, is allowed just to rest upon the surface of the mercury in the open siphon end of the tube at A; it consequently rises and falls as the column B E becomes longer and shorter, and the motion of the thread turns the pulley and moves the index through the arc of a graduated circle.

eter. Thus, supposing the length of the equiponderant column at any given time to be 30 inches at the level of the sea, at the height of

5000	feet it would be . . .	24.797 inches.
10,000	" "	20.499 "
15,000	" " . . .	16.941 "
20,000	" "	14.000 "

§ 47. The mean height of the barometer at the level of the sea is very nearly 30 inches, but a very little observation will prove that it is subject to perpetual oscillations within the limits, in this country, of about two inches and a half; these are dependant upon agencies which we will endeavour to develop at a more advanced period of our inquiry. We may at once, however, remark, that the existing pressure of the atmosphere regulates the elasticity of every portion of aeriform matter enclosed in jars or bell-glasses inverted over water, or any other liquid. If such a glass be carefully turned down upon the water-bath, so that the water may stand at the same level both inside and out, it is clear that it will enclose a portion of the atmosphere of the existing elasticity: supposing the glass to have been filled with water, and afterward with any elastic fluid, thrown up into it by that kind of upward decantation by which air, from its comparative levity, may be made to displace the heavier fluid, its elasticity must be governed by the same exterior pressure. It is necessary, therefore, to take the amount of this variable pressure into consideration, in taking the weight of any air by the process previously described (§ 44), and to assume some fixed pressure to which they may all be referred in taking their specific gravities. This standard pressure is 30 inches of mercury, and nothing can be more simple than the calculations by which observations made under any other pressure may be reduced to this standard: the law being kept in mind, that the weight is always directly, and the volume inversely, proportionate to the pressure. Suppose, for instance, that, with the barometer at 29 inches, we had found the weight of 100 cubic inches of air to be 29.9 grains, and wished to know what the weight would be at standard pressure; by the rule of proportion we shall find 29 : 30 : : 29.9 : 31.0. Or, suppose that we had measured 100 cubic inches of air at 29 inches, and wanted to know what the volume would be at 30 inches, we shall have 30 : 29 : : 100 : 96.6.(9)

§ 48. The atmosphere presses upon the surface of the earth, and upon the surfaces of all bodies which are plunged into it, with the same force as that by which it supports the mercury in the barometer; and a column of mercury 30 inches in height, whose base is one square inch, would weigh about 15 lbs., and would press upon the earth with the same force; every body, therefore, upon the surface of the earth, at the level of the sea, supports an average pressure of 15 lbs. upon every square inch of its surface. That we are not sensible of this pressure on our own persons and on all surrounding objects, is owing to its equality in all directions. From the fluidity of the atmosphere, the perfect mobility of its particles, any force is equally distributed throughout its mass, and its gravity not only presses downward, but upward and laterally, and in every direction alike. If we destroy this equilibrium, as we may easily do by the air-pump, the pressure becomes immediately manifest; almost the first stroke of the pump fixes the receiver to the plate, and after the air has been exhausted to the utmost we may raise the weight of the pump itself without detaching it. It is for the purpose of enabling them to bear this enormous pressure that such glasses are made of a spherical form. If a glass of a cubic shape be exhausted, it is speedily crushed to atoms; or if a bottle of a similar shape be hermetically sealed when filled with air of the usual density, and enclosed under a receiver from which the air is pumped, the elasticity of the included air no longer being counteracted by the exterior air, it will burst outward with equal violence.

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(9) The rarefaction of the air in any vessel connected with the airpump may be measured by gauges acting upon the principle of the barometer. In figure 4 (page 49), *k* represents a barometer-tube, opening under the receiver *f*, and dipping at its lower end into an open cistern of mercury. As the air under the receiver becomes rarefied, the superior elasticity of the atmosphere raises up a column of mercury, which, upon the supposition of the total abstraction of air, would stand at the same height as the barometer. The difference between the two, measured upon a scale of inches, indicates the elasticity of the residual air. The siphon-gauge at *i* does not begin to act till the rarefaction has been carried on to a very great extent. The upper part of the siphon is filled with mercury by boiling, which is kept in its place by the pressure of the air: when this is diminished to such a degree as not to be able to support a column of mercury equal in height to the upright part of the tube, it begins to fall away from the top, and to rise in the parallel leg of the siphon, and, as the equality of these two columns would denote a perfect vacuum above each, the elasticity of the air in the receiver, with which the instrument is connected, is measured by their difference.

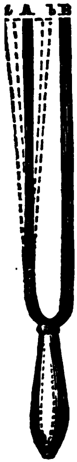
It is curious to remark how frequently common experience has anticipated science in the application, if not in the formal announcement, of scientific principles. A beautiful illustration of the expansive power of heat and the pressure of the atmosphere occurs in baking a fruit-pie. The cook inverts a cup in the dish, from which a portion of the air is expelled by the heat of the oven; when allowed to cool, the remainder contracts, and a partial vacuum being formed, the pressure of the atmosphere forces the juice to rise in the cup, and thus prevents its coming in contact with the crust, by which it would be absorbed.

§ 49. The surface of a man of ordinary stature is about 15 square feet, so that the atmospheri pressure upon his body amounts to 14 tuns; this h sustains with perfect convenience, because every cavity of his body is distended with aëriform matter of the same elastic force. He also moves about under this enormous load without being conscious of its existence, owing to the equality of its action. Could we suppose the air to cease to press in an upward direction, while its downward weight continued, he would be bound to the spot on which his foot rested as effectually as the rooted oak. Something of this we may indeed feel from the fatigue we endure in walking upon a stiff clay. In such a soil, the air is more or less pressed from under the feet; and just upon the same principle that the boy's plaything, called a sucker, raises the weight of a large stone, a strong effort is necessary to overcome this unequal pressure.

Those who ascend into the higher regions of the atmosphere by climbing lofty mountains or by balloons, often feel inconvenience in their ears and other cavities of their bodies from the included air not having time to adjust itself to the diminished pressure of the outward medium: and it is no wonder that persons of weak constitutions often feel considerable discomfort from sudden changes of the weather, when barometric oscillations may indicate a change of pressure upon their bodies of 1½ to 2½ hundred weight in the course of a few hours.

§ 50. The alternate action and reaction of mechanical force and elasticity, and the consequent propagation of force to a distance by vibration, are beautifully illustrated by the phenomena of sound. The complete development of the subject constitutes a distinct branch of science, under the name of *Acoustics:* we can only here advert to the play of the forces which are concerned in its production.

When the particles of an elastic body are suddenly disturbed by an impulse at a particular point, the force spreads throughout their substance from that point as a centre, and they return to their state of rest by a series of *isochronous vibrations* or rapid movements to and fro; equal numbers of which take place in equal times. The rapidity, force, and permanence of these vibrations depend upon the elasticity, the form, and the mode of aggregation of the particles of the vibrating body. They are not confined to the substance in which they are produced, but they communicate themselves to the surrounding air, in which, on account of its elasticity, they excite equivalent condensations and dilatations, which again are propagated to a distance. The corresponding impulses produced upon the ear constitute sound. If the successive impulses form a connected series, following each other too rapidly to be separately distinguished, they constitute a continued sound like that of the voice in speaking; and if they are equal among themselves in duration, they produce a musical or equable sound, as that of a vibrating string, or of the voice in singing. A quill striking against a piece of wood causes a noise, but striking against the teeth of a wheel or of a comb, a continued sound; and if the teeth of the wheel be at equal distances, and the velocity of the motion of a certain amount, and constant, a musical note.(10) The lowest sound which can be called musical is produced by 16 vibrations in a second of time; though, according to the observations of Dr. Wol



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(10) A B represent the two prongs of a tuning-fo made of steel; if one of them, A, be struck agai solid substance, it will momentarily assume th tion *b*, nearer to the other prong B, but from i ticity it will immediately return to its former p beyond which it will be carried by its momen the position *a*, about as far from A as the secon tion *b*, and thus a series of vibrations is brought which, being propagated through the air to th produces the sensation of a musical note.

ome ears are so constituted as to be able to ıte notes at both extremities of the scale re inaudible to others. The higher octave ound is produced by double the number of ıs, and the double octave by four times the in the same time, and so on in the progres- 32, 64, 128, 256; the last of which produces which is designated as the middle C on the rte. The fixedness of these relations is t the well-known sound of the different mu- :es has been employed by Professor Wheat- the measure of velocities in machines re utterly inappreciable by ordinary me- means.

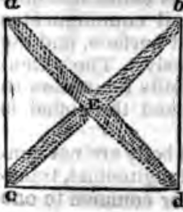
tain time is always required for the trans- of an impulse through a material substance, time varies with its hardness and compres- The velocity of sound in air has been experiment to be 1130 feet in a second; , 4900 feet; and along a deal rod, 17,400

As the force from the original impulse di- ı air, and spreads through a spherical space, ity must decrease as the square of the dis- ıt it is capable of being turned back or re- om the surface of any solid obstacle.

A musical string gives a very feeble sound rating alone, on account of the small quan- ir set in motion; but when attached to a face of wood, or to what is called a sound- l in musical instruments, it communicates ıtions immediately to that surface, and the stem vibrates isochronously. The exten- ating surface again transmits its motion to unding mass of the air, and the sound is reased.

The oscillations of a solid body are not con- ne direction, but may be longitudinal, trans- rotatory, in every plane, or confined to one

plane, ac ordingly as the impulse is commu
Differen s in the structure of a body may i
the dire ons of its vibrations. If a little
sand b trewed over a vibrating surface i
thrown to violent agitation by the force co
cated in particular situations, but in oth
tions i ll remain at rest, and it will thu
the eye distinguish the vibrating from th
cent pa . Thus, if vibrations be excited in
of glas metal. by drawing a bow across i
it will ound, and the sand
media in certain lines r
dispos accumulate from oth
and re It is thus found that
jacent face are in differen
of vib g always elevate
others ressed, d the oppositely v
parts are separated by lines of rest. The
of rest are termed *nodal lines*, and they vary
and position with the part where the bow i
across; but the point by which the plate is
ing necessarily in a state of rest, must be i
in a nodal line.(11) Similar points of rest,
points, are found on a vibrating string; and
of paper placed at the half, third, fourth,
aliquot points of its length, will remain on i
its vibration, but will instantly fly off from
termediate points. T y are points of equ



(1 If a plate of glass, *a*,
held orizontally at its centr
tween the finger and thumb, an
scattered over its upper surfa
causing it to emit a musical
drawing a violin-bow along its
sand will arrange itself in lines
ting regular figures, the form
will depend upon the pitch of
The lines *a* E,
ure, represent a
these nodal lines,
it is held, will be, of

between two adjacent oppositely vibrating parts. Indeed, all vibrating bodies have a tendency to divide themselves into a certain number of parts, which perform these vibrations independently of each other.

§ 54. The amount of force which may be accumulated from the frequent and regular repetition of minute impulses to the particles of elastic solids is very great, just as momentum may be accumulated in a pendulum by frequent small impulses (§ 29); and the cohesion of glass itself has been known to yield under the intense vibrations of a musical note. If we pass our moistened fingers lightly along a glass tube two or three yards in length, and from three fourths of an inch to an inch in diameter, we may generate a force which will be sufficient to move a leaden ball placed within it, and even to draw it up against the action of gravity, when the tube is inclined several degrees to the horizon. Or if we fix a small glass tube into a beam of wood, and cause it to vibrate longitudinally, in the same way, the successive and periodic impulses will be sufficient to agitate the beam throughout its mass, and to produce vibrations of such an extent, that whole handfuls of sand thrown upon it will be projected upon the lines of rest, which will thus be accurately defined.

§ 55. These vibrations alter the molecular arrangement and strength of bodies while they last, so that if a weight of 90 pounds be suspended from a copper band of three yards in length, 0.4 inch wide and 0.04 thick, it will remain unchanged for any length of time; but, if made to vibrate, it will become lengthened six or seven inches. M. Savart has lately measured the lengthening of rods of glass and brass by the act of vibration, under the friction of a damp cloth, and ascertained the amount of mechanical force which would be required to be directly applied to produce the same effect, and found it to be, in the first case (the diameter of the cylinder being 1.14 inches), equal to a weight of 2000 pounds; and in the second (the diameter being 1.38 inches), 3800 pounds. The facts are of the utmost practical consequence with regard to structures in metal which are destined to support great weights, and are, at the same time, exposed to regular oscillations and vibrations.

We will now direct our attention to the forces of

HOMOGENEOUS ATT[illegible] AND REPULSION.

§ 56. The force of COHE[illegible]n bodies is measured by the amount of any fo[illegible]hich may be required to separate their particle[illegible]reak them, and may be ascertained by experim[illegible] The opposing force may be applied in various [illegible]ays. 1. It may tend to tear the body asunder, in [illegible] direction of its fibres; 2. It may tend to break the [illegible]dy across; 3. It may tend to crush the body; 4. I[illegible] may tend to separate the particles by means of [illegible]on or twisting. The investigation of the stre[illegible]of materials, and the different degrees in whi[illegible] resist the action of force, so variously app[illegible]longs to mechanical science. The following ta[illegible] shows the force of cohesion from experiment [illegible] a few solids, as indicated by the weights required to tear them asunder and to crush them.

TABLE II.—*Of Strength of Materials.*

Bars 1 inch square torn asunder.		Cubes of 1-4 inch crushed.
Cast steel	140,000 lbs.	
Cast iron		10,000 lbs.
Cast copper	19,000 lbs.	7318 lbs.
Wrought copper	33,000 lbs.	6440 lbs.
Brass	17,000 lbs.	10,304 lbs.
Tin	4700 lbs.	966 lbs.
Lead	1800 lbs.	483 lbs.
Elm	5800 lbs.	1 in. cube
Pine	10,400 lbs.	
Oak	10,000 lbs.	

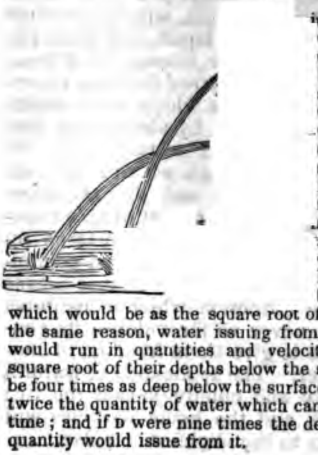
§ 57. The force of cohesion is opposed to mechanical force in the case of the surfaces of two solids of the same substance moving upon each other, and is estimated by the resistance to the motion, which is denominated *friction.*

Friction is greatest between rough surfaces, and diminishes with the degree of polish given to them.

All other circumstances being equal, it is directly proportioned to the pressure of the two bodies. Friction also arises from a similar opposition of the force of adhesion, in the case of the two surfaces in motion being of dissimilar matter; but it is greater between homogeneous substances than between heterogeneous ones.

§ 58. The subject of FRICTION, again, is purely mechanical; but we re-enter within the strictest limits of our department in considering next those adjustments of the two antagonist powers of homogeneous attraction and repulsion, which constitute the physical states of solid, liquid, and aeriform. The best, because most familiar, illustration of these three different states may be derived from our every-day observation of the changes which water undergoes. Every one knows that, by abstracting heat from water or cooling it to a certain point, we can convert it into a solid which we call ice; we diminish the repulsive force, and the attractive gains the ascendency. The amount of this cohesion we can estimate by the mechanical force required to disintegrate it; but pound it and comminute it as we will, we can never by these means totally overcome the attraction which constitutes its solidity; we can never so far unloose its constituent molecules as to give them freedom of motion among each other. The application of warmth will, however, gently and quietly loosen the tie; the ice will dissolve, and the liquid particles will yield in all directions to the slightest impulse.

§ 59. It is in consequence of the almost perfect manner in which cohesion is suspended in liquids that pressure is communicated by them in all directions alike. Solid bodies gravitate in masses, and exert no lateral pressure; but the particles of fluids gravitate independently of each other, and press against each other in every direction, not only downward, but upward and sideways. It is in consequence of this lateral pressure that water flows from an opening in the side of a vessel in which it is contained; and the lateral p ssure is the result of the downward pressure of th liquid above, and exactly equal to it: conseque y, the lower the orifice is made in the vessel, e greater will be the velocity of the water running ut of it, and the farther it will be projected from .(12) It is the same pressure acting upward wh h occasions water,



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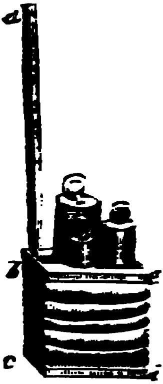
(12) If D be a hole made in the side of the vessel of vater, A, the water at D vould only be pressed by he simple weight of the erpendicular column of vater from A to D; but vhen the orifice at D is pen, and the water pernitted to spout out, its moion throws its whole colmn into action, and it will ow press upon and discharge the water from D vith the same force as if he water had been a solid escending from A to D, which would be as the square root of the height A D: and, for the same reason, water issuing from other orifices, C and B, would run in quantities and velocities proportionate to the square root of their depths below the surface of the fluid. If D be four times as deep below the surface A as B, it will discharge twice the quantity of water which can flow from B in the same time; and if D were nine times the depth of B, thre quantity would issue from it.

when [illegible] the same height [illegible] the other [illegible]

§ 60. But [illegible] particles which [illegible] out masses of [illegible]



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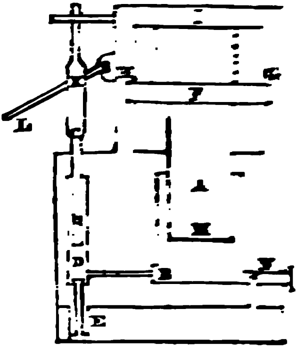
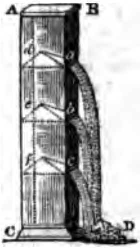


F 2

[illegible] former and any substance placed between the plates

§ 61. That imperfect destruction of cohesion, which is effected by mechanical force, is curiously contrasted with its perfect suspension by heat, by comparing this equal pressure of liquids with that of sand or some other finely disintegrated solid. If we pour sand into one leg of an inverted siphon, it will not mount in the other, and will even extend a very little way into the horizontal part. Whatever pressure be given to its upper surface will exert no influence on the issue below. A half-hundred weight placed upon it will produce no difference. The weight is not merely supported upon the base of the column, as in the case of a solid, but by the sides of the containing tube. The lateral pressure, however, does not vary with the height, as in the case of a liquid; but sand will flow out of lateral apertures made in a box in which it is contained with equal velocity, whatever may be the height of the column within.(15)

Single grains of sand, placed upon a flat surface, do not begin to roll until it is inclined between 30° and 40°, and this is the angle at which the pressure is exerted when this motion is resisted. The angle formed by a heap of shot or pease is 30°; and the weight of a pyramid, whose sides are inclined at this angle, is alone supported by the base, whatever may be the height of the column confined above it.(16)



I F, thus becomes violently compressed. The pressure is immediately relieved by turning the screw N, by which the water is allowed to flow back into the reservoir.

(15) A B C D represents a box filled with pure dry sand: if equal slits, *a b c*, be made in one of its sides, equal quantities will flow from them in equal times, and will be projected to equal distances, notwithstanding the difference in the heights. This figure should be compared with figure 12, which represents the flowing of water under similar circumstances.

(16) If sand be allowed to fall from a height C upon a flat sur-

A very simple mode of showing this effect is to take an open tin tube of any length, an inch in diameter, and to press a piece of thin paper, with the edges moistened, against the end of it, letting it adhere simply by such moisture; then placing the tube upright, with that end upon a table, to fill it with sand, and afterward gradually to raise it; whatever the weight of the tube and its contents, it may be carried anywhere in that position, although the paper bottom adheres but very slightly.

§ 62. After the cohesion of ice has been suspended, a farther accession of heat will convert the liquid water into a highly elastic aeriform fluid, which is commonly known by the name of steam. The repulsive force acquires the ascendency; the constituent particles tend to fly from one another, and are only restrained by the pressure of that surrounding atmosphere which regulates the elasticity of all aeriform matter which is not insulated from its action. The progress of this change of state is not so obvious and familiar as the preceding, but it is

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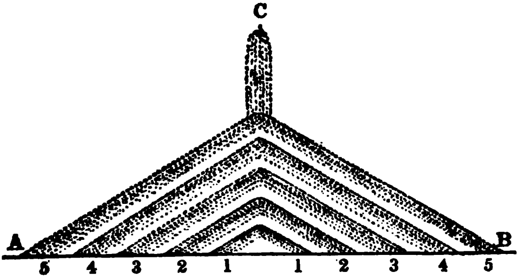
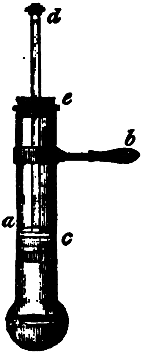
face A B, it will form at first the small cone 1 1, which will increase to 2 2, 3 3, &c., and, as it rolls down, will always maintain a conical surface whose inclination to the base is about 30°. The direction of the pressure of the sand in the box A B C D, fig. 15, and its equality, is represented by the pyramids *d e f*.



easily illustrated by experiment. If
tube blown at one end into a bulb,
leathern piston fixed to a hollow r
which is capable of being closed wi
cause a little water to boil in it un
steam will presently issue with sc
the passage, in the rod, which is to
the purpose of giving it vent. Up
passage the elastic force of the st
mulate till it forces the piston to
tube.(17) This force may be insta
by removing the bulb from the sou
blowing upon the tube: the aerifor
sume the liquid state, and the pre
upon the upper side of the piston
counteracted by the elasticity of t
under side, it will be forced down t
the tube. A fresh application of h
the elastic force, it will again be for
repetition of the process this little m
engine may be kept in action. Wh
liquefaction and vaporization take p
gradually; why a mass of ice doe
melt, or any body of
steam, upon reachir
temperatures, will b
we come to treat of
extraordinary agent
these transformation

§ 63. There is grea
pose that all unorgani
be susceptible of sin
state; that every soli
the state of a liquid,
form body; and that



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(17) *a* represents the g
bulb at its lower end;
which it is held; *c* is the
which passes through a c

eous body might be reduced to the liquid, and even solid state. Our command over the forces of nature does not extend so far at present, but the phenomena which we will farther examine are so general as to justify the conclusion that they are universal.

§ 64. With regard to solids, we distinguish several properties as modified results of the force of cohesion; namely, hardness, elasticity, brittleness, malleability, ductility, and compressibility.

§ 65. The relative *hardness* of a body is determined by its capability of scratching or being scratched by other bodies. It has no relation whatever to density; for lead, which may be easily scratched by the nail, has a specific gravity more than three times that of a diamond, the hardest substance in nature; neither is it connected with tenacity and brittleness, for iron is easily scratched by glass. It is needless, however, to dwell upon a property which every one is in the habit of appreciating.

§ 66. *Elasticity* is that property which we have already exemplified by the flexure of a spring and the torsion of a thread of glass; in consequence of which, the particles of a solid yield to a certain extent when force is applied to them, but immediately fly back to their original position when the disturbing power is withdrawn. Elastic bodies vary much in the extent to which they yield without breaking, and in the degree of perfection with which, after the displacement of their particles, they return to their former state. A piece of caoutchouc, or Indian-rubber, is very elastic, but not perfectly so, for it becomes permanently elongated by stretching. Glass, on the contrary, is perfectly elastic, for it will retain no permanent bend: when drawn into a fine thread, it may be twisted round upon its axis many times without breaking; and when set free, always returns to the point from which it set out.

§ 67. *Brittleness* consists
which a disrupture takes pl
of a solid, from a slight ch
them beyond the limits of
longs to most hard and ela
exemplified by glass and st

§ 68. *Malleability* is the
into thin leaves by hammer
ent degrees of perfection a
may in this way be beat in
282,000 of them would only
thickness of an inch. Silv
wise capable of being ex
leaves; and tin and lead i
much greater thickness.

§ 69. *Ductility*, or the ca
into thin wire, is not, as m
the concomitant of malleal
of being beaten into thin l
into wire finer than a hum

§ 70. *Compressibility.*
their density permanently
force; when thus compr
neously return to their f

§ 71. In liquids we ha
sion predominates to a
particles yield among e
impulse, and communic
alike. The force requi
in any sensible degree i
ved means of experim
trived, they were ac
has been found that, b
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pression is one twent
lowing table represe
experiments of Prof
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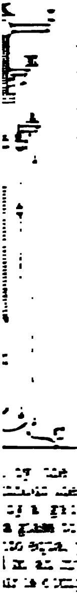
[illegible]



[illegible]

[illegible]

TABLE III.—*Compression of Liquids.*

	Millionth parts per atmosp
Mercury	2.65
Alcohol	21.65
Water	46.65
Ether	61.65

§ 72. Certain differences may be observed in still remaining cohesion of different liquids. T we distinguish *viscous* and *limpid* liquids.

Viscidity is that quality which renders the h geneous particles less moveable among one ano and is the direct opposite to limpidity. It is a ification of cohesion somewhat analogous to leability in solids.

It may be regarded as a kind of approach t solid state, but is distinguished from mere c sion; for if two drops of a viscous fluid are br into contact with one other, they run together much less velocity than two drops of a more fect fluid.

Oil and sirup are specimens of viscous, mer and spirits of wine, of limpid liquids. Some s like glass, become viscous by heat in their pas

column of compressed water, which may easily be seen without. By a similar apparatus, constructed of met enable it to bear a higher pressure, Professor Œrsted mea the compressions of air to 65 atmospheres. For this purp small index, fixed by a hairspring, was placed in the u gauge, which, being pressed forward by a column of me was left at the extreme point to which the liquid was f and thus registered the pressure. The amount of the pression was also registered by the simple apparatus H which is an opén vessel containing mercury, in which is p a glass vessel A B C D E, drawn out into a slender tub and turned down, as shown in the figure. This vessel is with air and placed in the receiver, and, when pressure plied, the effect is to drive the mercury up the tube E D, the vessel C B, compressing the air above it and falli bottom of that vessel. The volume of this metal, bei to that which was contained in the tube, will equal th by which the air was compressed during the experime o complete liquidity, while others, like water, become perfectly limpid at once.

§ 73. Aeriform fluids are commonly and conveniently distinguished into two classes; namely, *vapours* and *gases*. Steam will illustrate the first, and he air which surrounds us the second. We have seen that the slightest abstraction of heat proporionatety reduces the elasticity of steam, and condenses it into the liquid state. The slightest increase of pressure beyond the force of its own elasticity will produce the same effect, unless a simultaneous increase of heat enable it to sustain t; but the greatest reduction of heat which art can produce (and its command in this respect is considerable), and the greatest pressure which can be applied, have never yet succeeded in bringing the particles of atmospheric air within the verge of cohesive attraction.

§ 74. Other gases, however, which but lately were considered to be as permanent as atmospheric air, have yielded to the ingenious manipulation of Dr. Faraday. His method consists in generating the gas in a confined space, when, from the narrow compass into which it is obliged to pack itself, the mutual compression of its own particles is so great that they come within the limits of their self-attractive force, and assume the liquid state. It is true that the elastic force increases as the compression; but the energy of the cohesive force, when its limit is attained, in a much higher degree; not in the inverse proportion, that is, to the distances of the particles from one another, but as the squares or, probably, some higher power of the distances. Different gases yield to different degrees of compression; a pressure equivalent to two atmospheres is sufficient to produce the liquefaction of some, while carbonic acid requires thirty-five atmospheres, or a pressure of 525 lbs. upon the square inch of surface; and although experiment has yet failed to produce the effect, fair analogy justifies the hypothesis of geologists, that atmospheric air may exist in the liquid state in cavities of the compressed strata of the globe.

§ 75. The difference between a vapour and a gas, it may be observed, is one of degree and not of kind; for the aeriform fluid, which in the compressed tube floats above the liquefied portion of the gas, is strictly the vapour of the liquid portion, and is influenced by precisely the same circumstances as the vapours of liquids, which exist as liquids under atmospheric pressure alone.

§ 76. There are one or two other circumstances attending the reaction of the antagonist forces of homogeneous attraction and repulsion which ought to arrest our attention. When a liquid is about to assume the solid state, if the heat be very slowly withdrawn, and it pass very gradually under the influence of cohesion, the particles do not rush together into a confused *amorphous* mass, but sometimes build themselves up into geometrical solids of the greatest beauty and symmetry. This phenomenon is familiar to us in the freezing of water; so familiar that it does not excite half the attention and admiration which it ought to inspire: we see it in the ice which forms upon our windows in the winter's night, in the hoar-frost upon the trees, and in the construction of flakes of snow. The seemingly endless variety of figures which these substances present is limited by certain laws, and the lines which bound them form among themselves no angles but those of 30°, 60°, and 120°. If we melt a mass of sulphur, or of the metal bismuth, in an earthen pot, and when it has become slowly cooled, so as just to become crusted over, pierce the crust and allow the liquid portion to flow out, we shall find the cavity , latter studded with beautiful cubic forms whi most skilful carver could not rival,(19) and that of the former with no less beautiful six-sided prisms and needles.

The forms are denominated *crystals*, and the process is called *crystallization*.

§ 77. The assumption of the solid form is often attended with the exertion of an uncontrollable expansive or repulsive force, proving again the porosity of solids, the particles of which the prejudices derived from common observation would induce us to believe were in the closest contact.

This phenomenon cannot be better exemplified than in the passage of water into ice. Indeed, the common experience of a hard winter places the proof before us, in the bursting of pipes in which water is carelessly allowed to freeze; and if we take a small piece of a gunbarrel, securely plugged at one extremity, and closely fitted at the other with a screw, fill it with water which has been boiled to exclude the air, carefully close it, and place it in a situation where it may freeze, at the moment of solidification the barrel will burst with a considerable report.

The specific gravity of ice, compared with water, is 0.92.

Iron likewise enlarges its bulk at the moment of solidification, and hence the [illegible]

[illegible]

[illegible]

[illegible]

moment of congelation, of which mercury is an example.

§ 78. Heterogeneous Adhesion.

We come now to the contemplation of the action and reaction upon each other of particles of matter of totally different kinds, of different essence and sensible properties: and the first force with which such particles have been endowed we may usefully distinguish from cohesion or homogeneous attraction (to which it is opposed), by the title of *adhesion* or *heterogeneous attraction:* we have already exemplified it by the wetting of glass by water.

We trace it in matter in all its physical states; *i. e.*,-whatever the antecedent adjustment of the forces of homogeneous attraction and repulsion may be; but it exists in different degrees between different bodies, and, possibly, between some bodies does not exist at all. A polished blade of iron is capable of being wetted by water, not, however, in so perfect a manner as glass; but to neither of these substances will mercury adhere. It would, nevertheless, be too hasty a conclusion to infer from this observation that there were no adhesive attraction between the particles of glass, or iron, and mercury; the attractive force may exist, but in these instances the homogeneous attraction of the particles of the liquid may be superior to it, and prevent its efficiency. A perfectly clean surface of platinum is capable of being completely wetted by mercury, but the thin film of extraneous matters which commonly adheres to this metal in its ordinary state effectually prevents their mutual action.

Guyton de Morveau measured the force with which different metals adhered to the surface of mercury, by suspending equal plates from one of the arms of a balance, and ascertaining at the other the weight which was in case required to separate them. He employed fresh mercury in each experiment, and the following table exhibits his results:

TABLE IV.—*Adhesion of Mercury.*

	Grs.		Grs.
Gold	446	Zinc	204
Silver	429	Copper	142
Tin	418	Antimony	126
Lead	397	Iron	115
Bismuth	372	Cobalt	8

§ 79. The action of cements, in permanently fixing the surfaces of solids together, is dependant upon this force. For this purpose some substance in a soft or liquid state is interposed, which is capable itself of solidifying and drawing the surfaces together by this species of attraction. In this way wood may be attached by gelatine or glue; porcelain by albumen, or white of egg, and lime; and bricks by mortar; so that the adhesion of the surfaces of junction may offer even greater resistance to disruptive force than the cohesion of any other part.

§ 80. The heterogeneous adhesion of solids to each other is also of the greatest practical importance when it assumes the form of friction, that is, of superficial opposition to mechanical force, or the motion of two bodies in contact (§ 57). All other things being equal, friction is less between surfaces of dissimilar matter than between those of the same matter; thus the resistance of iron, moving upon iron, is expressed in terms of the pressure by the fraction 1-3.5, while that of iron upon copper is only 1-6th. The interposition of substances whose force of cohesion is small, such as plumbago or grease, greatly decreases friction; thus the resistance of iron upon iron is diminished to 1-10th by the application of tallow, and of iron upon copper to 1-11th. The complete investigation of this opposition of forces belongs to the science of mechanics; it would, however, have been a defect in this preparatory view not to have indicated an antagonism of forces on which we are dependant in almost every action of our lives. It is friction which prevents our feet slipping back every time we attempt to advance a step, and those who have attempted to walk upon polished ice well know how to appreciate the passive resistance of heterogeneous adhesion.

§ 81. A beautiful example of the adjustments which take place of the two antagonist forces of homogeneous cohesion and heterogeneous adhesion, is afforded by the phenomena of what is termed *capillary attraction.* The simplest case of this action arises when we dip a glass tube of very fine bore (hence termed a *capillary* tube) into a liquid which is capable of wetting it; upon attentively examining the appearances presented by such an arrangement, we shall find that the liquid rises in the tube to a certain height above the usual level, and assumes a concave surface at its upper extremity. We shall also observe, that on the exterior surface of the tube, as well as where it is in contact with the containing vessel, the liquid will stand above the general surface.

Now we have here three forces concerned; the force of gravitation, by the action of which upon the moveable particles of the liquid the general level of the mass is maintained; the interior force of homogeneous attraction, drawing the similar particles together, and resisting any force which may tend to separate them; and the exterior force of heterogeneous attraction between the solid and the liquid. The latter has power to draw up the included liquid (which is cut off by the glass from the action of the homogeneous attraction of the surrounding mass) against the action of the two former forces to a point at which they are all in *equilibrio*; and this power increases in some high ratio inversely as the distance; so that, the nearer the approximation of the active particles, the greater the elevation. This is not only shown by the gradual upward curve of the liquid, as its distance from the solid decreases, but may be demonstrated by varying the size of the tube, when the rise of the liquid will be found to increase rapidly as the diameter decreases.

It is in consequence of the concave surface of the liquid thus produced that the particles are drawn inward by their own attraction with less force than when the surface is plane, and the consequent diminution of pressure from without, inward, is made up by an additional column of the liquid.

The same action may be strikingly illustrated by dipping the ends of two plates of glass in coloured water, at a very small and gradually decreasing distance from each other; the water will rise between them, and the force increasing as the distance diminishes, will be shown by the *hyperbolic curve* of the upper surface, the heights of the different points of the surface of the water being inversely proportional to the distances from the angle, a property of the curve which is thus called by mathematicians.

§ 82. If, on the other hand, the liquid into which the capillary tube is plunged be incapable of wetting it, that is to say, if the homogeneous attractive force should be superior to the heterogeneous attractive force, a different order of phenomena will arise, but illustrative of the same principles. A fine glass tube, thus immersed into mercury, will exhibit a depression of the internal column of liquid below the general level; the upper surface will be convex instead of concave; and at the point of contact, both of the exterior of the tube and of the surface of the containing vessel, the liquid will be depressed. The forces concerned in the phenomena are the same as before, but now the homogeneous attraction has the superiority. The mercury within the tube is cut off by the inactive surface of the glass from the homogeneous attraction of the surrounding mass; its own self-attractive force, therefore, acts as from its centre, drawing its particles together, and causing them to assume more or less of a globular aggregation, according to the same law which determines the spheroidal form of a suspended drop of liquid. The increase of pressure from without, inward, which is the consequence of the surface being convex instead of plane, is balanced by a diminution of the column. The amount of this action is also inversely proportionate to the diameter of the tube.(20)

§ 83. Capillary action is of great importance in many natural and artificial arrangements; and, as familiar instances of it, we may refer to the absorption of water by a piece of sponge, and to the beautiful manner in which the flame of a lamp or candle is supplied with the liquid combustible by its ascent in the wick. The parallel interstices of a bundle of small wires will perform this office as well as fibres of cotton, which are commonly employed, and,

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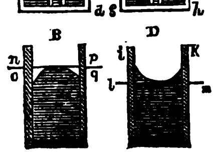
(20) C D represents a capillary tube, immersed in a liquid capable of wetting it, in the vessel *e f g h*. The liquid stands at a considerable height above the general level of the liquid, and is also drawn up by the sides of the containing vessel and the exterior surface of the tube, so as to form a curve between them. The form of the surface of the liquid within the tube is shown at *i k l m*. A B represents a capillary tube immersed in a liquid which is incapable of wetting it. The liquid is here seen depressed below the general level, and its surface in the vessel, *a b c d*, is curved from the depression which also takes place at the points of contact at its surface and the exterior surface of the tube. The form of the surface within the tube is shown at *n o p q*.



being incombustible, may be perpetually used, provided they be kept clean. The natural pores of vegetable bodies are also well adapted to the spontaneous ascent of liquids, and it is probable that the motion of the sap of plants is considerably dependant upon this power. The fact may be pleasingly exemplified by dipping one end of a piece of cane into spirits of turpentine, which will rise to the other, and may be ignited.

It is by this force, again, that water is imbibed by the porous materials of the earth's surface, and moisture distributed in due proportions to the roots of vegetables. The amelioration of soils by culture is brought about by changes effected in them in this respect; and the influence of differences, even in their original constitution, may be traced in the superior verdure of chalk hills over those of sand or gravel.

§ 84. The action of filtration, to which the chymist is so frequently obliged to recur, is also dependant upon capillary action. The pores of the filter become wetted by the liquid, and transmit it to the under surface by a force of *adhesion* which is independent of the pressure. When once it has penetrated it collects into drops, by the force of *cohesion*, which fall from the force of gravity. Not only may solids be thus separated from liquids, but liquids which imperfectly mix from each other. For this purpose the filter must be previously wetted with the liquid which it is intended to transmit, when that alone will pass, and the other be rejected. In this manner spirits of turpentine and water may be parted from each other.

§ 85. Few persons, perhaps, are aware of the prodigious amount of the force which may thus be called into action, and which may be measured by the opposition which it is capable of overcoming. If a dry plug of wood be tightly fitted into one end of a stout tube of glass or porcelain, and a projecting portion be allowed just to dip into water, the wood will swell with such force, by the intrusion of the liquid into its pores, as to burst the tube, though capable of resisting a pressure of more than 700 lbs. on the square inch. This power is turned to an economical account in parts of Germany and France, for separating blocks from the solid rock for millstones. Holes are bored in its substance, into which wedges of dry wood are tightly driven, and, when these are exposed to moisture, they swell, from the capillary action, and effectually split it in the direction in which they have been placed.

§ 86. The same kind of attraction and superficial action takes place between solids and aeriform bodies, although not so open to common observation: but an easy experiment will illustrate the fact. Take some of the fine dust of magnesia, and sift it carefully upon the surface of some water, in a tall glass jar, and it will presently become wetted by the liquid, and sink to the bottom in consequence of its specific gravity being something more than twice as great. Take, again, some iron filings, and sift them in the same manner upon the surface of water, and although their specific gravity is nearly four times greater than that of magnesia, they will float upon the top. A stratum of considerable thickness of the metal may thus be laid upon the liquid, which at length will sink in considerable masses, when it may be seen that they had been previously buoyed up by the adhesion of particles of air, which their accumulated weight will even carry to the bottom with them. The surface of each fragment of metal had been (we cannot, perhaps, say *wetted*, but) *enfilmed* with the gaseous matter, which prevented it from being wetted by the water; in the case of the magnesia, its attraction for the air was less, and, consequently, it was more readily displaced by the water.

The force of adhesion of air to glass is very considerable, and [illegible] construction of [illegible] with clean [illegible] ciously [illegible] these may be [illegible] ble to pass [illegible] inclination [illegible] coated [illegible] be removed [illegible] this process has [illegible] creep down between [illegible] the glass. [illegible] mately [illegible] the vacuum. [illegible] eters in this way [illegible] vented by [illegible] of the tube, and [illegible] contact of the [illegible] and the [illegible] is another [illegible] sion.*

§ 87. Some [illegible] ing and retaining [illegible] ter; and newly-[illegible] of taking up the [illegible] gases, its own volume [illegible]

TABLE V.—[illegible]

Ammonia	[illegible]
Muriatic acid	[illegible]
Sulphurous acid	[illegible]
Sulphuretted hydrogen	[illegible]
Nitrous oxide	[illegible]
Carbonic acid	[illegible]

It will appear from [illegible] others hereafter [illegible] are the most readily [illegible] liquids, yield most readily [illegible] neous adhesion. When charcoal already saturated with any one gas is put into another, it gives out a portion of the gas already absorbed, and takes up a portion of the new gas.

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* DANIELL's Meteorological Essays [illegible]

Aqueous vapour is also very greedily imbibed by newly-burned charcoal, some kinds of which will take up as much as 18 per cent. of their weight by a week's exposure to the air.

Though charcoal possesses this property in a very eminent degree, it is by no means the only substance whose pores exert the force of heterogeneous adhesion. Certain animal and vegetable textures absorb aqueous vapour so readily and regularly, that their changes of dimensions which ensue have been taken as measures of the amount of vapour existing in the atmosphere to which they have been exposed. Thus, the untwisting of a piece of catgut, or the beard of the wild oat, the elongation of a thin slice of whalebone, all afford good *hygroscopes*, or indications of the state of the air with regard to moisture; and the elongation or contraction of a human hair, properly prepared, is still observed at the Paris Observatory as a *hygrometer*, although the observations cannot be relied upon, and better and accurate methods have been devised for determining a point of great importance to science.

All these substances give up the moisture which they have imbibed when exposed to a dry atmosphere, and return more or less accurately to their original dimensions.

§ 88. The adhesion of gaseous matter to liquids is demonstrated every time we pour water from one vessel into another; large quantities of air, strongly attached to its surface, are carried by the momentum of the falling mass below the surface, and, becoming more elastic from the compr
detach themselves, and rise again in a strea
bubbles. We see this process upon an imm

scale in natural falls of water, where the [illegible] the dashing of the spray is [illegible] the escaping air [illegible] has been taken of this [illegible] being received into [illegible] pression, is applied to the [illegible] for the working of metals.

§ 89. It is not only in this [illegible] air becomes attached to water [illegible] adhesion [illegible] is made to distribute itself equally through the mass, however deep. The aeration of water [illegible] most important [illegible] quietly and [illegible] operation, the [illegible] creation, both animal and vegetable [illegible] with the vital air upon which their existence depends. If we take a quantity of [illegible] place it in a glass vessel under the receiver of the airpump, and exhaust the air, [illegible] ly transparent and [illegible] far reduced as to [illegible] temperature. But if we allow a quantity of [illegible] boiled water to remain in contact with the [illegible] some hours, and afterwards place it under the receiver, almost from the first stroke of the pump, we shall find bubbles of air forming in the mass, the greatest part of which will be attached to the surface of the glass, and will there adhere [illegible]ing in size, they finally make their escape. The air may properly be said to have been dissolved in the water; and thus we are led to consider the processes of *solution* and mixture as instances of the force of adhesion, although they are commonly referred to the action of the higher forms of chemical affinity.

§ 90. In seeking out the laws which limit these actions, let us first return to the mutual action of liquids and solids. We have seen that when a piece of clean platinum is dipped into mercury, force of adhesion between the two metals is s cient to overcome the cohesion of the liquid wh thus adheres to the solid, and wets it. If fo plate of platinum we substitute one of tin or l the same effect will be produced, and either m will be immediately wetted by the quicksilver; if we now leave them immersed in the liqui farther effect will be produced, and the force of hesion will be so strong as not only to overc the feeble cohesion of the liquid, but the strong mogeneous attraction of the solid itself: the cess of solution will take place; the solid will *dissolved* in the liquid.

Let us now select a more familiar instance lump of loaf sugar, just immersed in water by small point of contact, will quickly draw the liq up into its pores by capillary action; but the fo of adhesion proceeding beyond this will spee break down the solid textures, which will disapp in the water. We may vary the illustration w any soluble salt. We may judge of the energy the force which is thus called into action, gentle is the process, by estimating that which it o comes, namely, the cohesion of the solid, by effort which we must make to break its m Whatever tends to diminish the antagonist fo promotes and hastens the process of solution; every one knows, from common experience, that mechanical pounding or breaking of a lump of su or salt will considerably facilitate its solution. have seen the facility with which glass becon wetted with water; if we dimininish its cohes by mechanical force, a portion of it will be solved by the liquid; and upon placing some v finely pulverized flint glass upon turmeric pap and wetting it, the yellow colour of the paper be turned to brown by the action of the solution

§ 91. The action of a solvent upon a solid over, limited by its cohesion: when the *homo-* *us* and *heterogeneous* forces are exactly bal- l in the solution, the solvent is said to be *satu-* . With regard to water, the point of *saturation* ifferent bodies, even of the same class, varies much; thus at ordinary atmospheric temper- s, an ounce of distilled water will dissolve its weight of sulphate of ammonia; one third weight of sulphate of soda; one sixteenth of ate of potassa; and not more than one five redth of sulphate of lime. Water, however, h is saturated with one salt, will still be capable ssolving another.

2. The mechanical disruption of a solid, even e finest levigation, is, as we have seen (§ 61), very imperfect mode of diminishing the force hesion; the finest conceivable particles which hus be detached, consist, probably, of a count- multitude of its ultimate atoms, which are still ly bound together by homogeneous attrac- but by the application of heat we have it in ower to counteract the latter force, by a re- on of the like intimate nature; and by so doing ncrease the effective antagonist force of hete- eous attraction. The action of a solvent upon id is, therefore, much increased by raising its erature. Water may thus be saturated with a t the common temperature of the atmosphere; if heat be afterward applied, will dissolve an ional quantity; if the solution be then allowed ol, the attraction of cohesion will resume its dency, and the additional portion of the salt be deposited in a regular solid form.

ere are, however, two or three remarkable ptions to this general law. Water, at the erature of 32°, will dissolve 1-656th of its ht of lime; at a temperature of 60° it will up no more than 1-750th; and when boiling, 1-1280th; so that, when lime water is boil- portion of the lime is precipitated or ag-

gregated into small crystalline grains.
bility of sulphate of soda in water als
singular law: after having increased ra
temperature of 92°, where it is at its m
diminishes to 215°, at which temperatur
nearly of the same solubility as at 87°.
niate of soda is another salt which
anomaly of the same nature. Exception
laws of this kind, although not unde
facts of extreme interest, and generally
commencement of a clew, by following
may be led farther in the labyrinths
knowledge.

§ 93. As the force of heterogeneous
thus capable of overcoming the force
neous attraction, so is it capable of rest
keeping down the force of homogeneous
and gases are susceptible of solution
and as the point of solution of solids is
by the antogonist force of cohesion, so
said to be saturated with a gas when th
heterogeneous adhesion and self-repulsi
actly balanced. We have just seen that
ric air may be thus united with water,
kinds of aeriform matter are capable of
to a much greater extent. Water will
own bulk of carbonic acid, whatever it
may be, provided an equivalent amount
be maintained upon its surface. Soda-w
kept ready for immediate effervescence
chanical compression of this acid up
which it begins to make its escape the
pressure is relieved. By heating this
whole of the air may be expelled, fo
course, increases the repulsive force, a
it to overcome that of adhesion.

§ 94. But there are other gases which,
taken up by water, are not capable of
separated by any increase of temperature

of adhesion between them is so strong, that they remain united when both are in the self-repulsive state. Thus muriatic acid or ammoniacal gases are absorbed by water with a rapidity which is quite immeasurable, and, when the solutions are of a certain strength, may be distilled without change; they rise together in the elastic form, and are again condensed by cold.

§ 95. This will aptly introduce to our notice the exertion of this force by bodies in the same physical state, as the action of liquids upon liquids and gases upon airs or vapours. Such combinations are termed mixtures, and, unlike solutions, are unlimited by any antagonist force, either of attraction or repulsion.

Some liquids, however, are incapable of this incorporation or mixture: thus oil and water may be mechanically mingled together by agitation, but, as every one knows, spontaneously separates again in the completest manner. Here we may suppose that the forces of cohesion and gravity, which both oppose adhesion, are superior to the latter. Some few liquids mix together in a very minute proportion of them, as ether and water. If these two liquids be agitated together, by far the largest portion of the former will separate from the latter and float upon its surface. This is, in fact, a case of solution, the point of saturation of which is determined by cohesion and gravity: most liquids, however, mix together, and particularly with water, in the most perfect manner, in all conceivable proportions, and against the greatest differences of specific gravity: thus a drop of oil of vitriol or of alcohol will become perfectly diffused through a gallon of water, or a drop of water through a gallon of vitriol or spirit. The specific gravity of sulphuric acid is almost double that of water, and yet the difference, combined with its remaining cohesion and that of the water, is not sufficient to sep-

rate the two. The progress of the
e shown in a very interesting manner by
ome water with some vegetable blue; and
ly pouring it, by means of a small tube,
surface of the acid, in a tall glass jar: at the
of contact of the two liquids, and to a small
above, the blue water will be immediately
by the acid; but, if the experiment be
made, the colour of the great bulk will be
ed, and the jar will exhibit three perfectly
strata, of colourless acid below, of mixed
water of a red colour in the middle, and on
the blue unmixed water. In this state of thi
process will proceed; the heavy acid will be
attracted upward, and its course will be
the change of colour. That the mixture is
duced or assisted by any currents in the liqui
be manifest from the lines of junction of the
ent colours, which will remain perfectly shar
defined, and horizontal, during the progress
experiment, which will not be complete for
or four days. A similar experiment may be
with coloured alcohol and water, and in both
the mutual penetration will ultimately be perf

§ 96. Aeriform bodies are capable of mixi
gether in the same way as liquids; and as the
no remains in their case of efficient cohesive
to oppose the force of adhesion, they are all
ble of rapid diffusion through each other's
and there is no limit to their incorporation
is no point of saturation. If a portion of hyd
which is an inflammable gas, and the lightest
ponderable substance, be confined in a stro
and a portion of oxygen, a supporter of c
tion, and sixteen times heavier, in a simila
and the two be connected together by a
tube three or four feet long, the hydrog
placed above, in the course of a short
heavier air will be drawn up by the lighter

r drawn down by the heavier, so that a per-
nd equal mixture of the two will take place
n explosive compound [illegible]
ials; and the same property [illegible]

In the same way, if water be [illegible]
receiver of perfectly dry air, evaporation will
diately commence, and vapour of [illegible]
tension as that which at the same temperature
would rise in [illegible]
e. Dr. Dalton, to whose clear views [illegible]
t science is greatly indebted, expressed this
al fact by stating that one gas acts as a
n with respect to another [illegible]
ean to assert that the process [illegible]
place with the same velocity as [illegible]
acuum: because the particles of the gas [illegible]
ived, afford a mechanical impediment to the
ess of the other, but that the ultimate result is
me.

'. It is scarcely possible duly to appreciate, in
ist economy of terrestrial adaptations, the im-
ice of this mechanism by which gases and va-
rapidly permeate each other's bulks, and be-
equally diffused. The atmosphere which
inds the globe consists of a mixture of sever-
iform fluids in certain fixed proportions, upon
roper maintenance of which, "by measure
y weight," the welfare of the whole organic
on depends. The processes of respiration
ombustion are perpetually tending to the de-
ion of these nicely adjusted proportions, by
straction of the vital air, and the [illegible]
other which is a deadly poison to [illegible]
et, by the simple means which we have [illegible]
d, the poisonous air is not allowed to [illegible]
e, but diffuses itself instantly through the
ling space, while the vital [illegible]
er tendency, to supply the deficiency [illegible]
cal consumption has created. [illegible]

variable uniformity of this mixture, which is one of the most surprising phenomena where all is admirable. The most accurate examination has been made of air which has been taken from localities the most opposed to each other in all the circumstances which can be perceived to affect its purity; by means of a balloon, from a height of 22,000 feet above the level of the sea; from the surface of the ocean; from the heart of the most crowded districts of the most populous cities; from the summit of Mont Blanc; from within the Polar Circle; and from the Equator; and no difference has been detected in the proportions of its principal constituents. We shall return to this subject when we touch upon the properties of the differents kinds of matter which constitute this wonderful mixture.

§ 98. The most usual practical mode of separating bodies which are united by the force of heterogeneous adhesion, is by effecting changes in their physical states by means of changes of temperature. If it be required to recover a solid from its solution in a liquid, the solution is placed in a shallow pan or basin, and heat applied, when the liquid will be *evaporated*, and the solid remain. If it be necessary to preserve the liquid also, as a valuable product, the process is carried on in close vessels, and the vaporized liquid, after quitting the solid, is condensed by refrigeration in a separate vessel. The process is called *distillation*, and may also be applied to mixtures of liquids of different degrees of volatility.

The abstraction of heat, and the consequent decrease of the force of self-repulsion, or the increase of homogeneous cohesion, may also occasionally be employed for the same purpose. Thus, by the application of cold the aqueous part of sea-water may be frozen, and a strong brine will remain behind; or brandy, or any other mixture of water and alcohol, may be frozen so as to leave the spirituous part nearly in a state of purity. Vapours, again, may be separated from gases by a reduction of temperature; but other forces must be had recourse to for the separation of mixed gas, on account of the inadequacy of all ordinary means to affect their physical state.

HEAT.

§ 99. We have already traced the origin of homogeneous repulsion, the antagonist force to homogeneous attraction, or cohesion, to that cause, whatever it may be, which produces in us the sensation of heat: it is necessary that we should now inquire with more precision into the nature of this subtile agent, and the laws which regulate its action.

And first, with regard to the active sources of its abundant supply: the principal of these is the sun. The most inattentive observer cannot have failed to remark that the direct rays of the sun—some communication that is from that splendid but distant globe, which we designate by rays—impress him with the sensation of heat; and without this benign influence upon the animate and inanimate creation, all nature would be bound in the adamantine chains of cohesion: and could we imagine man to exist for a moment upon the face of the globe under its privation, vain would be all his puny efforts to remedy the defect from artificial sources of this life-preserving agent. The conflagration of every combustible upon the face of the earth would be insufficient to compensate for twenty-four hours the absence of the glorious orb of day.

§ 100. The second source to which we may advert, we may distinguish as mechanical, and consists in the friction, or rubbing together of solid substances. In this operation strong mechanical force is opposed to the forces of cohesion, or adhesion and heat is generated by the reaction of the two.

From some late experiment of M. Becquerel, it appears that when a rough body is rubbed against another with a smooth surface, the former becomes hotter than the latter. When polished glass is rubbed against cork, the first becomes the hotter in the proportion of 34 to 5: ground glass becomes hotter than cork in the proportion of 40 to 7. Silver and cork—the first becomes hotter than the second, in the proportion of 50 to 12. No change in the state or qualities of bodies, thus acting upon each other, necessarily accompanies the evolution of heat; neither is it necessary that they should be of different natures, or possessed of any opposition of qualities. Many familiar instances of high degrees of heat, derived from this source, will readily occur to a reflecting mind.

Two pieces of wood, rubbed together, speedily become hot; and when the force and the velocity are great, so much heat may be involved as to occasion combustion. The axles of the wheels of machinery or of carriages not unfrequently take fire from this cause; and it is well known that certain tribes of Indians, with a dexterity and address which we do not possess, have so far applied observation to practical purposes, that they are in the habit of kindling their fires by this means.

The sparks of the common flint and steel consist of small particles of the metal struck off by the stone, and burning under the influence of the heat elicited by the blow; and every one has had an opportunity of observing the more copious display of fire from the same source at the knife-grinder's wheel.

In some parts of the United States, where the mechanical force of falling water is abundant, the surplus power of certain mills has been most ingeniously turned to good account, by causing large plates of iron to rub against each other, and a ing the heat thus evolved to the warming of building. The most remarkable circumstance attending this source of heat is, that it is absolutely unlimited: so long as solid bodies can be made thus to act mechanically upon each other, heat is given out.

Count Rumford endeavoured to ascertain how much heat was actually generated by friction. When a blunt steel borer, three inches and a half in diameter, was driven against the bottom of a brass cannon, seven inches and a half in diameter, with a pressure which was equal to the weight of 10,000 lbs., and made to revolve thirty-two times in a minute, in forty-one minutes 837 grains of dust were produced; and the heat generated was sufficient to raise 113 lbs. of the metal 70° of Fah.; a quantity of heat which is capable of melting six pounds and a half of ice, or of raising five pounds of water from the freezing to the boiling point. When the experiment was repeated under water, two gallons and a half of water, at 60°, were made to boil in two hours and a half.

§ 101. The third source is chymical, or the action of particles of dissimilar or heterogeneous substances upon each other, accompanied by complete change of properties. All cases of common combustion, all our artificial processes for obtaining light and heat, are familiar examples of this action. The changes which take place in the active bodies during this evolution of heat, it will be a principal part of our business to inquire into hereafter: we have only at present to remark, that the heat evolved in each case, however copious and intense, is limited and proportionate to the quantities of the re-acting substances.

§ 102. The fourth source of heat, but probably nearly allied to the last, is electrical. That force which we have recognised as arising from the friction of glass or resins, by operating upon larger surfaces, may be accumulated in the form of a spark, which will ignite combustible substances. This action we must also refer to future investigation.

§ 103. A fifth source is physiological, and exists in ourselves. Heat is a product of animal life: we are conscious of this in ourselves; we can feel it, and we can judge of it by our sensations, when communicated from other persons and other animals: we can increase it in ourselves by muscular exertion; our hands and our faces burn, and in this state we can communicate the sensation of heat to others.

Heat and cold, in fact, when referred to our sensations, are but comparative terms, and depend upon the temperature of our bodies at the time of experience. If we raise the temperature of one hand by plunging it in hot water, and at the same time cool the other in cold water, upon removing both into a basin of tepid water, the same water will feel warm to one hand and cold to the other. Any estimation, therefore, of temperature by sensation must necessarily be extremely vague.

§ 104. Now, in none of these various actions of material bodies, which we have thus recognised as sources of heat, is there any loss of material substance. Notwithstanding the copious evolution of this wonderful agent, the quantity of the active matter—its weight—remains the same, whether combination ensue or not.

This something, then, which is generated in ourselves, or which may be communicated to us from any of the sources which have just been named, which we recognise by our sensations, and denominate heat, may be communicated also to every form of matter without increase of weight; and these can again impart it to us without loss of ponderable matter.

Thus a piece of iron placed in the direct rays of the sun will soon feel warm to our hands; or, when made red hot in the fire, will communicate heat to us éven at a distance; but its quantity of ponderable matter will be neither increased nor diminished.

The accession of heat, and consequent increase of repulsive force among the homogeneous particles of matter, not only determines the changes of state from solid to liquid, and from liquid to aeriform, which we have already noticed (§ 62), but produces expansion of bulk in bodies in all these states; and we must now inquire into the laws of this expansion, and the steps of the progress of a body from one physical state to another.

§ 105. The increase of bulk for the same increase of heat, differs very much in the different classes of substances. In solids it is small; in liquids greater; and in aeriform bodies the greatest of all. It also differs in bodies of the same class. By accurate measurement, it has been ascertained, that in raising the temperature of the following solids from the freezing to the boiling point of water,

Lead expands in volume		. .	1-350th
Iron "	"	. .	1-800th
Glass "	"	. .	1-1000th

that is to say, 350 cubic inches of		Lead	become	351
800	"	Iron	"	801
1000	"	Glass	"	1001

by this accession of heat.

The subjoined table includes the most interesting results of the best experiments upon the subject:

Table VI.—*Linear Dilatation from the Freezing to the Boiling Point of Water.*

1000000 of	Glass tube	become	1000861
"	Crown glass	"	1000875
"	Platinum	"	1000856
"	Cast iron	"	1001111
"	Steel	"	1001189
"	Gold	"	1001460
"	Copper	"	1001712
"	Brass	"	1001783
"	Silver	"	1001890
"	Tin	"	1001937
"	Lead	"	1002867

The expansion in volume may be obtained, without sensible error, by trebling the number which expresses its increase in length, where, as in the above instances, the fraction of its length is small.

By the same change of temperature, the following liquids augment their volumes in the annexed proportions:

1000 parts	of water	become	1046
1000 "	of oil	"	1080
1000 "	of quicksilver	"	1018
1000 "	of spirits of wine	"	1110

But every aeriform substance, provided it be not in contact with a liquid, expands in the same proportion; one thousand parts of air becoming 1373, by being heated from the freezing to the boiling point of water.

These expansions take place gradually, and when the heat is withdrawn the bodies return to their original bulks, by corresponding regular contractions.

§ 106. Now the perfection of science depends upon accurate measurement and instrumental precision: there can be no advance of a single step without these essential means. The unas senses are by no means sufficient to dete quantities with anything approaching to the necessary degree of exactness. The hand, or the application of muscular force, may indeed inform us that one body differs very greatly from another in gravity; but without the balance to determine weights which would be wholly inappreciable in this way, the science of chymistry could not have existed. So our sensations may inform us that one body is hotter or colder than another; but without some means of measuring differences of temperature which would wholly fail to affect our senses, our knowledge of heat would have been small indeed.

It is by observing that expansion or enlargement of volume is always produced by the same causes, which affect us with the sensation of heat, that we come to regard expansion as the indication of heat, and as this is an effect which can be ascertained with the utmost precision, we adopt its measure as that of the cause which produces it.

If a certain quantity of air, or of a liquid, or solid, undergo an augmentation of volume which we can determine when exposed to a certain source of heat, and, when we expose it to another source of heat, that expansion is doubled, there is reason to infer that the intensity of the second source is double that of the first. And this is the principle of that useful instrument the thermometer.

§ 107. The honour of the first invention is generally ascribed to Sanctorio, an Italian physician, about the year 1590; but the same contrivance probably suggested itself in an independent manner to Cornelius Drebel, about the year 1610. One thing, however, is certain, viz., that it dates from about the beginning of the seventeenth century.

The thermometer of Sanctorio consisted of a hollow glass globe, attached to a long stem, open at the opposite extremity; a portion of air was expelled from it by the expansive force of heat, and the end of the tube was then immersed in a colour-

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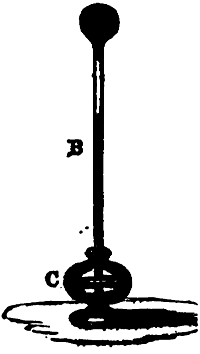
ed liquid.(21) As the included air cool turned to its former volume, the liquid r tube, from the superior elasticity of the air pressing upon the external surface of t A scale of equal parts was applied to the which the expansion of the included air f or its contraction from cold, could be mea the movement of the column of liquid liable, however, to the objection of bei upon, not only by the expansion of the air, but by the barometric changes of the atmosphere.

§ 108. Air has not only the advantage extremely regular in its expansion, but als cating very minute changes of temperatu great alterations of volume which it underg being heated and cooled; and a modificati air-thermometer is now very often used in researches. It was invented in the year was chiefly brought into notice by the s experiments of the late Sir John Leslie. It of two thin equal glass balls, united toge tube bent twice at right angles, the balls be ated at the top of the dicular arms, and cut any communication w atmosphere. Both ba tain air, but the greate the tube is filled with



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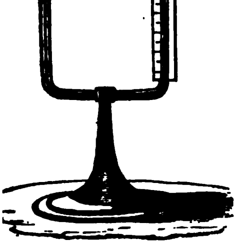
(21) Air thermometer of B is the stem of the instru upper end of which terminat pacious ball, while the low low the surface of the liqu vessel c. When a portion been expelled from the bal and it is afterward cooled, th elasticity of the outward ai column of liquid in the stem

d liquid.(22. This instrument cannot be affected y any change of temperature acting alike upon oth the balls, for the pressure on the opposite surices of the included liquid will in such cases be lways equal; but it will instantly indicate the ightest difference of temperature between the two alls; for the elasticity of the air on one side being reater than on the other, the liquid will be forced ›wards the side where the temperature is the lowst, and the difference may be measured upon a :ale. The instrument has hence been named the *ifferential thermometer.*

§ 109. The first great improvement in the therıometer for ordinary purposes was made by the ıembers of the Italian Academy del Cimento, in 660, who substituted the expansions of a liquid as ıe measure of heat; enclosing it in a glass ball and ıbe, which was afterward cut off from all commuication with the variable atmosphere by softening ıe extremity of the glass at the flame of a lamp, ıd hermetically sealing it: the instrument thus at once became more accurate and more manageable. Spirits of wine was the liquid first employed, and quicksilver was afterward used by Halley and Sir Isaac Newton: both liquids are now, at times, employed for different purposes.



§ 110. Still the thermometer wanted much of per-

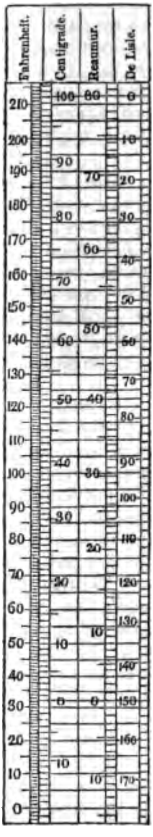
(22) Differential Thermometer of Leslie. The liquid in the two stems is shown at the same level as when both balls are exposed to the same temperature: any difference can be accurately measured upon the attached scale.

fection; for different instruments thus constructed could not afford comparable results, although experiments made with the same instrument were comparable with one another. For the last great improvement we are indebted to Newton. It had been observed by another eminent philosoper, Hook, that the temperature of melting ice was always fixed and permanent; and that the temperature of boiling water was equally invariable, provided the pressure of the atmosphere did not change. The sagacity of Newton pointed out the application of these observations to the completion of the instrument. If we immerse the mercurial thermometer in melting snow or ice, the liquid will gradually contract, and sink in the stem to a certain point, and then stop; and, however long we may allow it to remain in the ice, it will sink no lower. The experiment, repeated at any time or in any place, will afford the same results; the liquid will always sink to the same part, and no farther. By marking this we obtain one fixed point, which must be the same in every thermometer which is subjected to the trial. If we now remove the instrument into a vessel where it may be surrounded with boiling water, while the barometer indicates an unvarying pressure of thirty inches, the liquid in the glass will expand till the mercurial column reaches a certain height, where it will again become perfectly stationary, and afford another invariable point of comparison. The distance between these two points measures the amount of expansion of the whole quantity of the included liquid; or, rather, is the measure of the difference of the expansion of the liquid and the glass; for both expand. Upon the supposition that the expansion of the two is equable, and that the bore of the glass tube, in which the liquid moves, is equal throughout, the distance between the two points may be divided into any number of equal parts, and the equal amounts of expansion or contraction measured by them may be taken to indicate equal differences or increments of temperature, which will correspond in all instruments similarly graduated upon this principle; and, moreover, that the law of expansion continues the same both above the boiling and below the freezing point of water, an extension of the same scale of equal parts will afford the means of measuring greater and less degrees of temperature with reference to the same fixed standard.

§ 111. It is much to be lamented that the philosophers of different nations have not agreed upon the arbitrary division of this important quantity; and, consequently, we have various thermometric scales which perpetually require to be reduced from one to the other in the different scientific communications. In this country it is divided into 180 parts or degrees; but the freezing-point is not designated by Zero, or 0°, but by the number of 32°, making the boiling-point of water 212° instead of 180°. This scale was introduced by Fahrenheit, a German artist, who conceived that he had obtained the lowest possible degree of cold by the mutual action of common salt and snow. If a thermometer be introduced into such a mixture, it will contract to about 32 1-180th parts of the expansion between freezing and boiling water, and thus the commencement of this scale, or 0, was placed at that point.

In France, the thermometer named Reaumur's was for a long time generally employed: the interval between freezing and boiling water in that instrument is divided into eighty degrees. The graduation commences at the freezing-point, and the boiling-point is the eightieth degree. It is still in general use in Russia.

The scale now generally adopted in France was originally proposed by Celsius, and used in Sweden. It commences also at the freezing-point of water, between which and the boiling-point the space is divided into 100 parts: hence it is now commonly distinguished by the name of the centigrade thermometer.(23)



Other divisions of the thermometric scale have at times been introduced, but have fallen into disuse.

Fahrenheit's division is founded on error, and is very arbitrary and inartificial; it has, however, two important advantages: 1st, The degrees are small, and hence it is less requisite than with other scales to use fractional parts, which, in observation, are apt to be neglected, and in calculation are inconvenient. 2d, The commencement of the scale being placed at a low temperature, we have seldom to express negative degrees; while, in the centigrade and Réaumur's, it is always necessary either to prefix the signs of minus or plus (— or +), or by terms to denote whether the number stated is above or below Zero.

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(23) These three divisions of the thermometer are laid down and compared in the annexed scale, together with another, by De Lisle, now in disuse, in which the space between the freezing and boiling points is divided into 150°, the Zero being placed at the latter.

Knowing the ratio of these scales to each other, nothing, of course, can be easier than to change the expression of their degrees from one to the other. Let it be required to know what 70° cent. is upon Fahrenheit's scale:

100 : 180 : : 70 : 126 and 126 + 32° (or the number of degrees from Fahrenheit's 0) = 158.

Or what is 74° Réaumur upon the centigrade scale:

80 : 100 : : 74 : 92.5.

It would not be difficult, in the present advanced state of science, to invent a division of the thermometric scale, which might at once be more philosophical and more convenient than any of those now in use; but nothing but the general consent of the leading scientific men in the principal countries where science is cultivated, would justify the attempt; which, without such an agreement, would only add to the perplexity and distaste which every one at times must feel from this multiplication of scales.

§ 112. It would be foreign to the object of this work to enter upon all the necessary refinement in the construction of a good thermometer; but every one should know how to test the goodness of instruments which everywhere abound. The principal point to be attended to is the equality of the bore of the tube; for if equal lengths have not equal capacities, of course a scale of equal parts will not divide the expansion equally. This may be ascertained by breaking off a portion of the thread of mercury in the tube, which may generally be done by a dexterous jerk, and, moving it up and down the tube, ascertaining whether it occupy equal spaces in every part. This is very seldom, indeed, the case; but a correction may easily be applied to the scale by marking off upon it spaces of equal capacity. The examination of the fixed points is not difficult; but when the range of the scale will not admit of this, an accurate comparison should be instituted with a standard instrument.

§ 113. When great degrees of cold are to be measured, spirits of wine is the liquid selected for the construction of the instrument, as it has never yet been congealed by the greatest degree of cold to which it has been possible to expose it; whereas mercury has been known to become solid even in the natural temperatures of the arctic regions. Spirit, however, passes into vapour at a temperature far below the boiling-point of water; and it is usual, therefore, to graduate thermometers made with it by comparison. Mercury is well adapted to most common purposes, as its congealing point is sufficiently low, and the upper part of its scale may be extended to nearly 600, in consequence of its high boiling-point.

The openness of the scale of a thermometer depends upon the relative capacities of the bulb and stem; the greater the former compared with the latter, the more the expanded liquid will be extended, and the larger will be degrees, and the more easy the observation of fractions of a degree. But the delicacy of the instrument, or the quickness with which it adjusts itself to changes of temperature, will depend upon the smallness of the quantity of the liquid, or of the matter upon which the change is to be effected.

§ 114. Dr. Brook Taylor was the first to confirm by experiment the hypothesis that equal thermometric degrees, or equal amounts of expansion, might be taken to represent equal increments of temperature. He took a pound of water, and heated it to the temperature, as indicated by a delicate thermometer, of 200°: he then took another pound, heated to 100°, and, mixing the two together with proper precautions, he found that the thermometer plunged into the mixture indicated a temperature of 150°, or the exact mean; as it should have been according to the hypothesis.

§ 115. The expansion of solids is equally applicable with that of aeriform and liquid bodies to the measurement of temperature; but as it is smaller than that of matter in its two other states, and can only conveniently be measured linearly, and n volume, it is by nice mechanical adjustments [illegible] that it can be rendered available to the purpose a compound bar be formed by accurately adjusting and screwing together equal plates of two metals, whose expansions differ considerably, such as iron and brass, and one of its ends be fixed to some support, upon the application of heat it will bend, the least expansible metal becoming concave: if, on the contrary, the temperature be lowered below that at which the adjustment is made, the greater contraction of the brass will cause the iron to become convex. Upon this principle a very sensible thermometer has been constructed by M. Breguet. It consists of a very thin riband of platinum, plated with silver, and coiled into the form of a helix: one end of this compound plate is fixed to an upright support, and to the other a delicate index is attached, moving over a graduated circle. As the temperature to which this instrument is exposed varies, the spiral twists or untwists, and carries the index round the circle, the degrees of which measure equal amounts of the contraction or expansion. The value of the degrees may be fixed by comparison with a standard thermometer of the usual construction.

§ 116. The use of the mercurial thermometer is limited to temperatures below that at which quicksilver boils, or to about 600°; and a method of measuring the high temperatures of ignition at which many of the processes of the arts are carried on having been long a desideratum of science, various methods have been proposed to supply the deficiency. The most celebrated *pyrometer* is that of Mr. Wedgwood. It consists of a metallic groove or gauge, the sides of which gradually converge; pieces of very pure clay are made into small cylinders, having one side flattened; and, being heated to redness, they are made just to fit the larger extremity of the groove. It is a property of clay, permanently to contract and become harder by exposure to a high temperature: not that this contraction is an exception to the general law of expansion by heat, but is owing to a change in the chymical constitution of the earth, which loses a portion of the water with which it is combined, and it was supposed that the amount was exactly proportioned to the intensity of the heat to which it is exposed. The amount of contraction in the clay cylinders, after being exposed to the temperature which it was desired to measure, was easily determined by allowing them to slide from the top of the groove downward, till they arrived at a point beyond which they would not pass. Mr. Wedgwood divided the whole length of this gauge into 240 parts or degrees, each of which he calculated to be equal to 130° of Fahrenheit's scale; and the Zero of his scale, indicating a red heat, corresponded, according to his experiments, to 1077°.

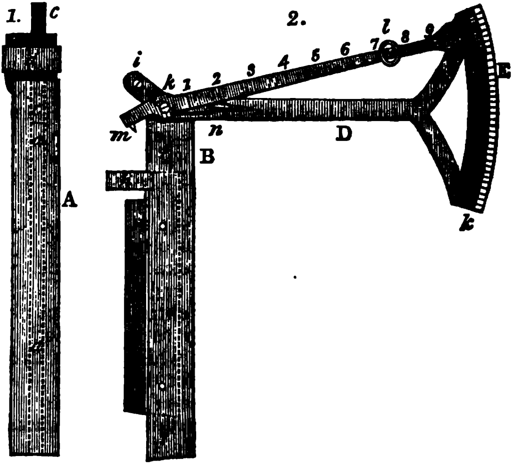
The difficulty of obtaining clay of uniform composition is of itself an almost insuperable objection to this method of estimating high temperatures; and it has been since ascertained, that the observation upon which it is founded is not correct; for clay will contract as much by the long continuance of a comparatively low heat as by a short continuance of a high one. Hence the degrees of heat which Wedgwood's pyrometer has been applied to measure, have been enormously exaggerated.

§ 117. The problem, however, may be easily solved by the accurate measurement of the linear expansion of bars of metal in a pyrometer which was invented by the author, and called by him the *Register Pyrometer.*

It consists of two parts, which may be distinguished as the register and the scale. The register is a solid bar of blacklead earthenware, highly baked. In this a hole is drilled, into which a bar of any metal, six inches long, may be dropped, and which will then rest upon its solid end. A cylindrical piece of porcelain, called the index, is then placed upon the top of the bar, and confined in its place by a ring or strap of platinum passing round the top of the register, which is partly cut away at the top, and tightened by a wedge of porcelain. When such an arrangement is exposed to a high temperature, it is obvious that the expansion of the metallic bar will force the index forward to the amount of the excess of its expansion over that of the blacklead, and that, when again cooled, it will be left at the point of greatest elongation. What is now required is the measurement of the distance which the index has been thrust forward from its first position; and this, though in any case but small, may be effected with great precision by means of the scale.

This is independent of the register, and consists of two rules of brass, accurately joined together at a right angle by their edges, and fitting square upon two sides of the blacklead bar. At one end of this double rule a small plate of brass projects at a right angle, which may be brought down upon the shoulder of the register, formed by the notch cut away for the reception of the index. A moveable arm is attached upon this frame, turning at its fixed extremity upon a centre, and at its other carrying an arc of a circle, whose radius is exactly five inches, accurately divided into degrees and thirds of a degree. Upon this arm, at the centre of the circle, another lighter arm is made to turn, one end of which carries a nonius with it, which moves upon the face of the arc, and subdivides the former graduation into minutes of a degree; the other end crosses the centre, and terminates in an obtuse steel point, turned inward at a right angle.

When an observation is to be made, a bar of platinum or malleable iron is placed in the cavity of the register, the index is to be pressed down upon it, and firmly fixed in its place by the platinum strap and porcelain wedge. The scale is then to be applied by carefully adjusting the brass rule to the sides of the register, and fixing it by pressing the crosspiece upon the shoulder, and placing the moveable arm, so that the steel point of the radius may drop into a small cavity made for its reception, and coinciding with the axis of the metallic bar. The minute of the degree must then be noted, which the nonius indicates upon the arc. A similar observation must be made after the register has been exposed to the increased temperature which it is designed to measure, and again cooled, and it will be found that the nonius has been moved forward a certain number of degrees or minutes.(24) The



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(24) 1. Represents the register; A is the bar of blacklead; *a a* the cavity for the reception of the metal bar; *c c* is the index, or cylindrical piece of porcelain; *d* the platinum band, with its wedge, *e*.

2. Is the scale by which the expansion is measured; *f f* is the greater rule, upon which the smaller, *g*, is fixed square. The

scale of this pyrome[illegible] that of the thermom[illegible] in boiling mercury. [illegible] stant as that of [illegible] curately determ[illegible] amount of expans[illegible] grees is thus determ[illegible] expansions may be [illegible]

§ 118. The [illegible] these expansions [illegible] opposing force [illegible] enormous. Some [illegible] is understood [illegible] which would be [illegible] in stretching or [illegible] they take place [illegible] increase its length [illegible] and quiet [illegible] stacle by which [illegible] equal to that [illegible] length by [illegible] withdrawing [illegible] power in [illegible]

Such a [illegible] to a variety [illegible] rected, and [illegible] construction [illegible] against.

The wheelwright [illegible] the iron [illegible] wheel a little [illegible] fellies, and [illegible] to the latter [illegible]

projecting [illegible] platinum [illegible] arc of the [illegible] centre. [illegible] upon the centre [illegible] and in the [illegible] throwing water upon it, and the contraction binds the whole together with enormous force. Upon the same principle the cooper heats the iron hoops of his casks, and firmly draws the staves together by cooling them in their places. The plates of the boilers of steam-engines are riveted together with hot rivets, which, when cool, draw them together and render their junction perfectly compact.

M. Molard, by an application of the same force, ingeniously restored the equilibrium of a building in Paris, the walls of which had passed outward by the incumbent weight. He introduced several strong iron bars through holes in the opposite walls, and screwed strong plates, or *washers*, as they are called, on the projecting ends, so as to bear tightly upon the walls. The bars were then heated by lamps, and consequently lengthened; in this state the washers were again screwed up, and, when the bars were allowed to cool, they contracted and drew the walls together to a small amount; a repetition of the same process gradually and safely effected the purpose.

The same process has been since applied in the restoration of the Cathedral at Armagh.

§ 119. Experience has taught engineers that it is dangerous to attempt to confine such a force as this, and that it is necessary to make provision for these expansions and contractions, particularly in the metallic constructions which are now so common. In iron pipes for the conveyance of gas and water, when the lengths are very considerable, some of the junctions are rendered moveable; so that, by the end of one pipe sliding into that of another, the accidental changes due to temperature are provided for.

The arches of the Southwark iron bridge rise and fall about an inch in the usual range of atmospheric temperature, and, if provision had not been made for this, destructive consequences must have ensued.

The steeple of Bow Church has within these few years been nearly thrown down by the alternate expansion and contraction of some rods of iron which were built into it to give it stability. The rods in hot weather lengthened, and lifted the incumbent mass of masonry; they returned in cold weather to their former dimensions, leaving the stones upraised; dust and small particles of matter made their way into the cracks thus produced; the rods again lengthened, and lifted the mass a little higher; till, by numberless repetitions of this slow but irresistible operation, the fabric was shaken to its foundation.

Even in the shoeing of a horse, injurious consequences will follow from neglect or ignorance of this principle. If a horseshoe be applied in a heated state, the hoof will certainly be injured by its subsequent contraction.

§ 120. A singular circumstance, accompanying the contraction of metal during great degrees of cold, was observed in some of the expeditions to the arctic regions, viz., that the astronomical instruments did not always, at once, take the adjustment due to the temperature to which they were exposed; but, upon concussion, they contracted suddenly to the regular amount.

§ 121. We have already noticed the greater expansion of liquids than of solids for equal increments of temperature, and the various amounts in different species. These expansions are generally regular, except when they are near their boiling or their freezing points. Near the higher point, their expansibility increases rapidly for equal increments, while considerable anomalies have been observed near the lower.

It has been stated (§ 19) that the law of expansion by heat and contraction by cold is all but universal; there is but one real exception to it known, and this occurs in water. It has been established by the most careful and decisive experiments, that water not only expands as we have noticed (§ 77) when passing from the liquid to the solid state; in the moment, that is, when its particles are taking up a new and regular arrangement under the prevailing force of cohesion; but increases its volume in the act of cooling some time before it reaches its freezing-point. The expansion commences when the temperature is reduced to about 40° of Fahrenheit, or eight degrees above the point of congelation, and it increases in an increasing ratio until the liquid solidifies.

The observation is easily made by means of two equal thermometers, the one filled with water and the other with spirit. When placed in melting ice, the latter will gradually fall to the freezing-point, while the former will descend to about 40°, and then begin to rise.

§ 122. From the alteration of volume which bodies universally undergo from changes of temperature, the necessity of attending to this circumstance in taking specific gravities will now be readily understood. These consisting of the weights of equal bulks of different kinds of matter compared with water, it is necessary that the temperature of the standard, and of the bodies with which it is compared, should be the same. The temperature of 60° has been adopted in England as a mean, which is most easily ensured in all situations and in all seasons; but that of 40°, when water has the greatest density, is better.

From the great dilatation which aeriform matter undergoes from increase of temperature, the correction of the measured volumes of different kinds of air is of the highest importance. It results from the accurate experiments of Dr. Dalton and M. Gay Lussac, that all experience equal enpansions by the same augmentation of temperature, and that 100 parts of air at 32°, being heated to 213°, expand to 137.5 parts: the increase being 37.5-100th of the original bulk.

Dividing this by 180, we find that a [illegible] dilates 1-480th of the volume which [illegible] 32° for every degree of Fahrenheit [illegible] universality of this law, as applied [illegible] of elastic matter, not [illegible] has been proved by experiment [illegible] the most opposite qualities [illegible] perature extending from the [illegible] to the boiling-point of [illegible]

§ 123. One of the [illegible] heat—for the accurate [illegible] are indebted to the [illegible] be rudely estimated [illegible] dency to an equal [illegible] or thirty substances [illegible] qually heated, [illegible] temperature in [illegible] is established by [illegible] and laws of which [illegible] quire.

CONDUCTION OF HEAT.

§ 124. If we take a [illegible] in the flame of a [illegible] disagreeable sensa[illegible] hot extremity [illegible] fingers: but if we take a [illegible] in the same [illegible] many times [illegible] long before any [illegible] by which the heat [illegible] called *Conduction* [illegible] without changing [illegible] cent particles [illegible] follows: If the [illegible] placed in communication with [illegible] heat, and we wait for [illegible] state of temperature, we shall find that tances from the source taken in arithmetical gression, the excess of temperature above the rounding medium will form a geometrical sion.

The property varies very much in different and from the above experiment we conclude the charcoal is a bad conductor, and the wire a conductor of heat. It may be roughly stated the most dense bodies possess the property greatest proportion. Thus metals are the best ductors; next stones; next hard woods, and

Table VII.—*Of Conduction.*

Gold	1000
Marble	23.6
Porcelain	12.2
Fine Clay	11.4

Diamonds and other gems are much better ductors of heat than glass, and thus may be di guished from it by contact with the lips, which general, are very sensible to changes of tem ture. The former substances will feel cool compared with the latter.

Metals themselves vary very much in their ducting power, so that if equal bars of silver platinum be each held by one of their extrem while the others are in contact with flame, the mer will burn us while the latter will feel sca warm. The following table exhibits the condu powers of different metals compared with gold

Table VIII.—*Of Conduction of Metals.*

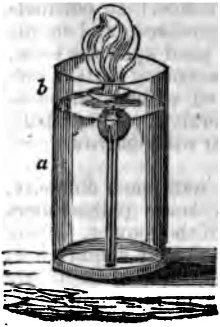
Gold	1000	Iron	3
Silver	973	Zinc	3
Copper	898.2	Tin	3
Platinum	381	Lead	1

§ 125. We have already noticed the vagueness any estimation of temperatures by comparing with our own sensation; the different conducting powers of substances will discover a new source of erroneous judgment from this test. In a room of uniform temperature, all the different inanimate substances may be of equal temperature; but if we touch substances of different densities and natures, very different sensations will be produced by them: a piece of metal will feel much colder than marble, stone, or glass; and these, again, colder than a wooden table or a book. The reason is obvious; each of these substances, although they would affect a thermometer equally, has a different conducting power; and that which is the best conductor will carry off heat from our bodies with the greatest rapidity, and, therefore, will produce in us the greatest sensation of cold.

§ 126. Many useful contrivances for the convenient management of hot bodies are dependant upon the differences of this property; as when a wooden handle is applied to protect the hand from a hot teakettle, or the handle of a silver teapot is insulated from the body by the interposition of small plates of ivory, which effectually prevent the conduction of heat to any inconvenient extent.

By breaking the cohesion of solids, their conducting power may be very much decreased; and on this account, by placing a layer of sand upon the hand, and carefully screening the surrounding parts, a red-hot iron ball may be supported without inconvenience. At the siege of Gibraltar, red-hot balls were carried to the batteries in wheelbarrows covered with sand.

§ 127. Liquids conduct heat with such difficulty, that it has been doubted by some philosophers whether they be not destitute of this power. From the facility, however, with which they acquire heat under particular circumstances, it might be hastily concluded that they possess it in an eminent degree: but this facility depends upon another property, which we shall presently examine. The imperfection of this property in liquids may be proved by a very simple and easy experiment. If we nearly fill a glass tube, four or five inches in length, with water, and heat the upper part in a spirit-lamp, we may cause the water to boil upon the surface, while we hold the tube in the hand without the slightest inconvenience, the water not being able to conduct the heat downward. It may be proved with greater precision by placing an air-thermometer in a glass jar, and filling the latter with water, so as to cover the bulb with a layer of the liquid, not more than the tenth of an inch in depth. Oil of the temperature of 400° may now be carefully poured upon the surface; or a capsule of inflamed ether may be floated upon it without affecting the thermometer.(25) This heat, however, will ultimately be conducted down the solid sides of the containing vessel; and the interference of this operation renders it difficult to make very accurate observations upon the subject; but it has, nevertheless, been proved by very delicate and ingenious experiments, that liquids do conduct heat, and differences in the power have even been detected in different liquids: mercury, for instance, being a better conductor than water, and water than oil.



§ 128. The difficulty of determining the power of conduction in aeriform bodies is still greater than in liquids. It has never yet been proved that they are capable of conducting heat at all; and common experience even may

(25) *a* represents the vessel of water, with the included air-thermometer; *b* is the capsule containing the inflamed ether.

ıce us that they are very bad conductors. A
imple experiment may afford a rough esti-
of the comparative powers of conduction in
ıree classes of solid, liquid, and aeriform
. Metals heated to 120° will severely burn a
laced upon them, owing to the facility with
the heat will travel towards it; water will
ald, provided the hand be kept without motion
ill it reaches the temperature of 150°, while
ntact of air may be endured at 300°. A thin
of either the liquid or air is cooled by the
t, through which the heat of the adjacent
es travels with great difficulty; but if the
e briskly moved about, and brought into con-
ith fresh particles, the water will be intoler-
a much lower temperature.

re is an experiment upon record, in the Phil-
cal Transactions, by Sir Joseph Banks and
who ventured into a room heated to 260°,
mained there a considerable time without
inconvenience: and in several processes of
s it is necessary for workmen to enter stoves
as high even as 300°, from which no inju-
ffects follow. Under such circumstances, all
t with metallic substances must be carefully
d, or severe injury would be sustained. The
roperty of non-conduction also preserves the
ı the opposite extreme of temperature; and
e voyages to the arctic regions prove that a
– 55°, or 14° below that of freezing mercury,
sustained without injury, provided the at-
ere be still; but if there be any wind, the
sive contact of fresh particles, even at much
temperature, will abstract heat with suffi-
apidity to freeze the extremities.

). The bad conducting power of the vapour
ids is strikingly proved by heating a bright
, or crucible of platinum or silver, to nearly
heat, and then throwing into it a few drops

of water. The liquid will be collected into the form of a flattened sphere, under the force of cohesion, and will roll about upon its axis to different parts of the heated surface without wetting it, being kept from contact by an intervening atmosphere of vapour. Under these circumstances it will slowly evaporate, but will never reach its boiling point. If the temperature, however, of the metal be allowed to fall, the liquid will come into contact with it, and will be converted into vapour with almost explosive violence.

The same phenomena are produced with water and heated iron; and another curious instance of the anticipation of science by common experience is afforded by the test which laundresses apply to ascertain the proper temperature of their smoothing-irons. When a drop of moisture, extemporaneously applied, rolls off the iron in a globule, they know that it is sufficiently hot; but when it adheres and boils, it is returned to the stove.

§ 130. Many useful applications are daily made of these principles to the purposes of convenience and of the arts. We put double doors, enclosing a body of air, to our furnaces, to prevent the heat from being conducted outward; and we double [illegible] our icehouses to prevent it from being conducted inward. We act upon the same experience in the selection of proper substances for clothing, to preserve our animal warmth: and articles of dress are warm in proportion to the quantity of air [illegible] they contain in their texture; furs, feathers, wool, and down, retard the passage of heat in this way; and, for the same reason, snow preserves the warmth of the earth in frosty weather.

Count Rumford measured the relative conducting power of different materials employed for clothing, by enveloping a thermometer in a glass cylinder, blown into a ball at its extremity, and filling the interstices with the substance to be examined. He heated the apparatus in boiling water, and then transferred it into melting ice, and observed the number of seconds which elapsed during the passage of the thermometer through 135 degrees.

Air alone required	576″	Raw silk	1284″
Lint	1032	Beavers' Fur	1296
Cotton wool	1046	Eider down	1305
Sheeps' wool	1118	Hares' fur	1315

The unerring Wisdom which providentially presides over the order of nature, changes the clothing of many animals as the seasons change: hair, at the approach of winter, being changed into wool, and feathers into down.

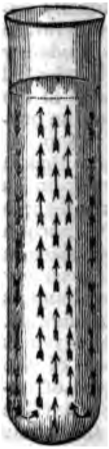
CONVECTION OF HEAT.

§ 131. Every one is aware that, notwithstanding the difficulty with which heat travels through liquid and aeriform matter by the process of conduction, that is, without disturbing the relative position of adjacent particles, both classes of bodies speedily become heated, and that equilibrium of temperature is brought about which it is always the tendency of heat to operate and maintain. This is effected by processes of circulation, or rapid change in the relative position of adjacent particles, and the process has been appropriately termed Convection.

When a liquid is heated, we have seen that it expands, and, of course, becomes lighter; from its great mobility, the heated and lighter particles rise to the surface of the mass, and a new portion comes into contact with the source of heat, rises in its turn, and so the whole is brought successively under its influence, and the motion will continue as long as heat continues to be thus communicated. The rapidity with which heat is thus conveyed is easily illustrated by the simple apparatus of the water in the glass tube (§ 127). If, instead of applying the flame of the spirit-lamp to the surface of the liquid, it be applied to the bottom, the whole mass speedily attains the boiling temperature, and becomes intolerable to the hand. The course of the currents by which the circulation is maintained is easily rendered visible by suspending some light powder, of about the same specific gravity, in water, in a glass flask.(26) The more a liquid is expanded by a given change of temperature, the greater will be the difference of specific gravity between the part which is heated and the rest of the mass, and the more rapid, therefore, will be the circulation from the change. Any tenacity and viscosity in the liquid will impede its motion, and when water is thickened with flour, or other farinaceous substances, it parts with acquired heat very slowly: many a person, however, has burned his mouth with hot porridge, and expressed his surprise at the slowness with which it cools, without being able to assign the philosophical reason of the phenomenon.

The circulation of heated water is now commonly and advantageously applied as a safe, economical, and regular means of warming hothouses and other buildings.

§ 132. The same process takes place, but much more rapidly, in elastic fluids; and in this class of bodies the equilibrium of heat is maintained by a circulation of the most perfect kind. Any one who has observed "the moats in a sunbeam," must have remarked by their



(26) The direction of the ascending and descending currents in a vessel of water heated from the bottom, is shown by the darts in this diagram. An ascending current sets up the axis of the cylinder, and is compensated by an equal quantity of liquid descending towards the circumference. If the heat be applied equally round the sides of the vessel, the direction of the currents will be reversed. The motion of the particles of light powder become very rapid, and the water is thus carried to its boiling-point.

motion, in almost every direction, the rapidity with which the ascending and descending currents of the air upon which they are borne intermingle; and upon looking across a heated body, as a chimney or a hot poker, the ascent of the heated column of air may clearly be detected.

The force with which it rises is indicated by the steady and tapering form of the flame of a candle, which consists of aeriform matter in a state of ignition. This heated current generally ascends perpendicularly in the surrounding cool medium, but may be diverted from its course by holding over it a long tube, in the axis of which it will flow, though greatly inclined from the perpendicular. The flame of a gas-burner may even be directed downward by connecting it with the shorter arm of a tube, bent twice, at right angles. The longer arm must have the air within it rarefied, by burning a little spirit of wine in a sponge, when an ascending current will be established, which will draw down the ignited gas, the heat of which will afterward maintain the draught in the chimney.

§ 133. The expansive and ascensional force of a body of hot air may also be illustrated by confining it in a bag of any light material, such as tissue paper. If the aperture of such a bag be held over the flame of a piece of sponge, steeped in spirit of wine, it will become distended and ascend in the air. Such was the power which Montgolfier first applied to the construction of a balloon, and in dependance upon this principle Pilatre de Rosier first committed himself to float upon the atmosphere.

§ 134. Some very interesting properties of aerial currents may be illustrated by placing a lighted taper in a flat dish, and covering it with a bell-glass, with a long chimney immediately over the flame. If a little water be placed round the edge of the glass in the dish, the air will be prevented from entering it, and the flame will speedily be extinguished for want of a fresh supply. If, however, the taper be again lighted, and the chimney of the bell-glass be divided into two channels by a diaphragm down the middle, and it be again placed over the taper, it will continue to burn for any length of time. The heated and light particles of the air, which tended to ascend in the tube in the former arrangement, but were impeded by the opposite tendency of the cold particles to descend, will pass out by an ascending current on one side of the diaphragm, while a contrary current of fresh air will continually compensate them on the other side; the direction of these currents is readily rendered visible, by mingling some cloudy or smoky substance with the descending current. This separation of contrary currents is of considerable importance in the ventilation of mines, and many deep shafts are divided by boarded partitions, to ensure the descent of fresh air upon this principle.

We are indebted to the expansion of air for the ventilation of our rooms and for the ascending currents in our chimneys, by which our fires are maintained. If we hold the flame of a candle to the upper part of a door opening into a heated room, we shall not fail to find, by the direction in which it is bent, that a current of light heated air passes outward; while, by lowering it to near the bottom, we shall be able to detect a counter-current of denser cold air rushing inward with equal velocity.

The knowledge of these principles, it cannot be denied, ought to have led to a more perfect system of ventilation than is commonly adopted in our public buildings, where crowds assemble for business or for pleasure; but this, unhappily, is not the only instance in which indolence prefers the well-beaten road of routine practice to the more laborious paths which better knowledge would point out.

§ 135 The convection of heat is a process of the utmost consequence also in some of the grand operations of nature; and it is principally by the circulation of fluids, elastic and non-elastic, of which their perfect mobility renders them susceptible, that the distribution of temperature over the earth is regulated, and those great inequalities guarded against, which would certainly result from the heating of the solid strata alone. Thus the atmosphere with which the globe is surrounded, moderates the extremes of temperatures both in the arctic and equatorial regions. When the surface becomes heated by the direct rays of the vertical sun, the stratum of air reposing on it is rarefied and ascends; its place is supplied by the denser air pressing in from the colder parallels, and by a constant succession of these operations the heat is moderated, which would otherwise become intense. The constant current of the trade-winds owes its primary impulse and direction to this cause. The constantly-ascending warm air, in its effort to maintain that equilibrium and equality of pressure which results from the laws of hydrostatics, must flow over towards the colder climates, and carry with it the heat with which it is charged, and thereby mitigate the extremes of cold. Currents from the poles and the equator upon the surface of the earth, and opposite currents from the equator to the poles, in the upper regions of the atmosphere, will therefore constantly exist, although their directions may be variously modified by inequalities upon the earth's surface, and other disturbing influences. The course of these grand compensating currents has often been traced by accidental circumstances. Some years ago, during an eruption of a volcano in the island of St. Vincent, in the West Indies, it was observed that the ashes were carried against the course of the winds: *i. e.*, against the course of the current upon the surface of the earth. The force of the explosion, or the ascensional force of the ascending column of heated air had, in fact, carried them into the upper stream, which was flowing in the contrary direction. Those also who have made the ascent of the Peak of Teneriffe, have constantly observed the wind blowing in the contrary direction on the summit, to that which prevailed at the foot of that mountain.

§ 136. Water is not less useful in this respect in the economy of nature. When a current of cold air passes over the surface of a large collection of water, it abstracts from it a quantity of heat; the specific gravity of the water is thereby increased, and the cooled portion sinks. Its descent forces up a portion of warmer water to the surface, which again communicates heat to the air passing over it, and this process may be continued for a considerable time, proportioned to the depth of the water. Currents are also formed in the ocean similar to those in the elastic atmosphere. The water which descends, when unobstructed, must spread at the bottom of the sea, and the denser water of cooler latitudes will flow towards the equator, and produce compensating currents upon the surface in opposite directions; and thus the ocean again tends to moderate the excessive heat of the torrid zone, as well as the intense cold of the polar climates. The Gulf Stream, as it is named, is an example of this action. This great current sets across the Atlantic from the coast of Africa, and, being deflected from the shores of the Gulf of Mexico, is carried northward to the banks of Newfoundland, in the neighbouring latitudes of which it may generally be detected by its effects upon the thermometer. An immense volume of warm water is thus transported to the cold regions of the north, where it cannot but have a considerable influence upon the climate. It is probable that the temperature of the westerly winds of our own island in winter is much influenced by this cause.

§ 137. And here we must not fail to observe the important and beneficial purpose effected by that singular exception to the general law of expansion by heat, which fixes the point of greatest density in water nearly eight degrees above its point of congelation (§ 121). When the whole mass of accumulated fluid, such as that in a deep lake, has been cooled down to the temperature of 40° by the perpendicular circulation which we have just considered, the vertical movement ceases, and the surface water becoming lighter as the temperature farther falls, soon sets into a sheet of ice. The subjacent water is preserved from the farther influence of the cold by the cessation of the circulation, and its almost perfect non-conducting power. If, like mercury, oil, and other liquids, its density went on augmenting to its freezing-point, the cold air would continue to rob the masses of its heat till the whole sank to 32°, and it would suddenly set into a solid rock of ice, and every living animal within it would perish. In these climates a lake so frozen could never again be liquefied; for the process of thawing necessarily beginning above, the heated and light water would lie upon the surface, and effectually prevent the convection of heat to the lower strata.

This observation is, however, only fully applicable to accumulations of fresh water: for the waters of the "great deep," another protection has been provided. Saline matter in solution in water, it has been ascertained, lowers both the point of freezing and the point of maximum density. The ocean, on that account, and because of its great depth, which renders it an almost inexhaustible store of heat, resists freezing still more effectually than the deepest natural reservoirs of fresh water, and is scarcely known to freeze, except in latitudes where the most intense cold prevails. Even then, it is the watery particles alone which congeal, to the exclusion of the saline, which, increasing the density of the lower strata, arrest their circulation, and thus preserve them from the superficial cold.

Heat of Composition.

§ 138. *Heat* and *Temperature* we have hitherto used as nearly synonymous terms, and all the effects of the subtle force, to which we have been directing our attention, have been accompanied by its free development, and have been measured by our sensations, and by the thermometer and pyrometer. We have now to trace it, entering, as it were, into the composition of bodies, losing its character of temperature, and becoming latent to our instruments and our feelings.

Equal volumes of the same liquid, at different temperatures, afford, upon mixture, the mean temperature of the two. A pint of water at 50°, being mixed with a pint at 100°, a thermometer immersed in the mixture will indicate a temperature of 75°. This result has already, indeed, been adduced in confirmation of the accuracy of the instrument (§ 114). If, however, a measure of quicksilver at 100° be agitated with an equal measure of water at 40°, the resulting temperature of the two will not be 70°, or the mean, but 10° lower, or 60°; so that the quicksilver will lose 40°, whereas the water will only gain 20°: yet the water must contain the whole heat which the quicksilver has lost. Hence it appears, that water has a greater capacity for heat than quicksilver: it requires a larger quantity of heat to raise it to a given temperature. The confirmation of this view may be obtained by the converse of the experiment; for if a measure of water at 100° be agitated with an equal measure of quicksilver at 40°, the resulting temperature will be 80°: the water will fall 20° in temperature, but in this fall will give out sufficient heat to raise the quicksilver 40°.

The same comparison may be made by weight, and will lead to the same conclusion. Thus, if a pound of quicksilver at 40° be agitated with a pound of water at 156°, the resulting temperature will be 152°.3: the water will lose 3°.7 of temperature, but enough heat will be evolved to raise the metal 112°.3. Now the proportion of 3°.7 : 112°.3, is the same as 0.033 : 1; hence, adopting water as the standard of comparison, we call the specific heat of quicksilver 0.033, designating by the term *specific heat* the heat peculiar to the *species* of matter compared with the standard

Again: If a pound of water at 100°, and the same weight of oil at 50°, be mixed together, the resulting temperature will not be the mean 75°, but 83°.5: the water, therefore, will lose 16 2-3°, while the oil will gain 33 1-3°; or, reversing the temperatures, the mean will be 66 1-3°, so that the oil will give out 33 1-3°, and the water will rise only 16 2-3°. Hence, the heat which will raise the temperature of oil 2°, will raise an equal weight of water only 1°; and the specific heat of oil will therefore be 0.5°.

§ 139. This different capacity of different bodies for heat must have a considerable influence upon their rates of heating or cooling: those which have the highest specific heat increasing or diminishing their temperatures most slowly under equal circumstances. Thus, if equal quantities of water and quicksilver be placed at equal distances before a fire, the metal will be more rapidly heated than the water; and again will cool down a certain number of degrees more rapidly when exposed in a cold place. Conversely, the specific heats of different bodies may be determined by carefully observing the time in which they cool down a certain number of degrees, and comparing them with water under similar circumstances. This method is susceptible of great accuracy, and may obviously be applied where mixture is impossible.

§ 140. A third method of ascertaining s heats was devised by MM. Lavoisier and La who contrived an apparatus for the purp which they gave the name of Calorimeter. instrument was liable, however, to some p objections, which have limited its use. Th ciple upon which it was constructed will another illustration of the nature of the ph non.(27) A certain weight of water, for in was surrounded with ice in a convenient ves

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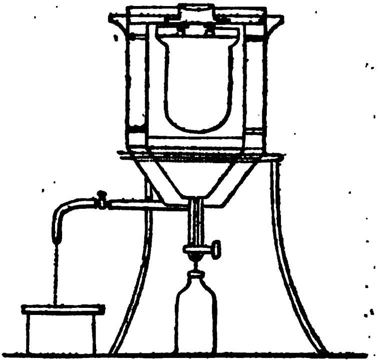
(27) The calorimeter consists of two similar meta sels, the one contained within the other, and kept sep small pieces of wood. The interval between the tw



with ice, broken small, and packed close. By consta newing this ice, as it melts by the heat of the atmosph interior vessel will be kept constantly at the temperatur The water which is formed is removed by a stopcock p the lower part of the interval between the two vessels. the interior vessel another still smaller vessel is sus formed of iron net, designed to hold the body to be coole interval between this third vessel and the second is al with ice: and the water which this latter produces in flows out of the lateral stopcock into a vessel which it, that it may be accurately weighed.
]

in passing from the temperature of 212° to 32°, the quantity melted was found to be a pound; an equal weight of oil, in cooling down through the same range of temperature, thawed only half a pound: and from this experiment we arrive at the same conclusion as from mixture and cooling, that the specific heat of water being reckoned as 1°, that of the oil is only 0.5°.

The following table exhibits the specific heats of various bodies referred to this standard from the best authorities:

TABLE IX.—*Of Specific Heats.*

Hydrogen Gas .	3.2936	Oxygen . .	0.2361
Water . .	1.0000	Carbonic acid .	0.2210
Aqueous vapour	0.8470	Charcoal . .	0.2631
Alcohol . .	0.7000	Sulphur . .	0.1850
Ether . .	0.6600	Iron . . .	0.1100
Oil . . .	0.5200	Mercury . .	0.0330
Nitrogen Gas .	0.2754	Platinum . .	0.0314
Air . . .	0.2669	Gold . . .	0.0298

§ 141. It has been shown, by the careful experiments of MM. Dulong and Petit, that the specific heat of bodies increases as their temperature rises; so that it requires more heat to raise them to a certain number of degrees when at a high than when at a low temperature. The specific heat of iron, for instance, was found as set down in the following table:

TABLE X.—*Specific Heat of Iron.*

From 32° to 212° . . .	0.1098
——— 392° . . .	0.1150
——— 572° . . .	0.1218
——— 662° . . .	0.1255

A similar law is maintained in other bodies, as shown in the following table:

TABLE XI.—*Progressive Specific Heat.*

	Between 32° and 212°.	Between 32° and 572°.
Of Mercury . .	0.0330	0.0350
Zinc . .	0.0927	0.1015
Antimony . .	0.0607	0.0547
Silver . .	0.0557	0.0611
Copper . .	0.0949	0.1013
Platinum . .	0.0335	0.0355
Glass . .	0.1770	0.1900

§ 142. It is probably from changes effected in the specific heat of bodies, that condension or approximation of their particles is attended with elevation of temperature, and dilatation or expansion with the opposite effect.

When spirits of wine and water are mixed together in equal measures, it may be shown that the bulk of the mixture is less than that of the two liquids in their separate states; and, in consequence, the temperature rises so as to become sensibly warm to the hand. In the same way, oil of vitriol and water contract on mixture, and so much heat becomes free, that some inflammable substances may be kindled, or water boiled, by its application. The sudden compression of air by the piston of a small syringe, disengages heat enough to kindle tinder exposed to it: while compressed air, suddenly allowed to expand, will become so cold as to condense all the vapour with which it may be mixed in the form of a cloud. If a delicate thermometer again be suspended in the receiver of an airpump, it will be found to sink during the process of exhaustion, and the cloud which commonly forms at the same time is owing to the same absorption of the heat of temperature.

§ 143. The increased capacity which air requires by rarefaction has an important influence in modifying the temperature of the atmosphere. The air, becoming rarer as it ascends, absorbs its own free heat, and hence becomes cold in proportion as it recedes from the surface of the earth from which it chiefly derives its heat. The average depression of temperature has been found to be about 1° of Fahrenheit's scale for each 300 feet of ascent. By this constitution of the atmosphere heat, so to speak, is economized: for if, instead of thus being absorbed and laid up in store, it had remained free, it would soon have become dissipated and lost. Other most important purposes are also effected by the progression of temperature which this law of specific heat has a tendency to maintain, to which we shall presently advert.

§ 144. When matter undergoes one of the great physical changes, from the solid to the liquid and from the liquid to the aeriform state, we find exemplifications of the phenomena of latent heat. As in these transitions a large quantity of heat is absorbed, combined, or fixed, so, in the opposite changes from the aeriform to the liquid and from the liquid to the solid state, heat is again liberated and becomes sensible.

It was Dr. Black who, about the year 1747, originally investigated the phenomena of latent heat with singular success, and his researches upon the subject rank among the most admirable efforts of experimental philosophy. The observation had, as has been before remarked (§ 110), previously been made, that the freezing and boiling of water always took place at certain fixed temperatures; but it occurred first to Dr. Black to inquire what becomes of the heat which, in either case, must keep continually flowing into the bodies while the processes are maintained.

Equal weights of water at 32° and of water at 212° will, as has been before explained, produce on mixture the mean temperature of 122°; but equal weights of ice at 32°, and of water at 212°, only produce, after the ice has melted, a temperature of 52: the water loses 160 degrees of temperature, while the ice acquires only 20°; 140° degrees of heat are therefore expended in changing the state of the ice from solid to liquid. Dr. Black, from this and similar experiments, drew the conclusion that this portion of heat became latent in the water; which owes its fluid state to this latent heat. That this heat is not destroyed or annihilated, will appear from considering that water, exposed to a degree of cold far below the freezing-point, will gradually part with its excess of temperature above that of the surrounding bodies, and become colder and colder till it reaches the freezing-point; but will not descend below 32° till the whole has become ice, and yet it must continue yielding up heat at the same rate as before. There must, therefore, be within it a continued supply of heat to keep it up to this fixed point: the moment the whole becomes concrete, the temperature will begin to sink, and will soon reach that of the surrounding objects and medium.

§ 145. Similar phenomena are observable in all cases of liquefaction; and we can produce artificial cold, often of great intensity, by the rapid solution of certain saline bodies in water; upon this principle the action of freezing mixtures depends, which are often applied economically to the purpose of cooling beverages in hot climates. The mere solution of nitre alone will lower the temperature of water at 50° to 35°, and four ounces of nitrate of ammonia, with four ounces of carbonate of soda, dissolved in four ounces of water at 60°, will in three hours freeze ten ounces of water in a metallic vessel immersed in the mixture while the solution is in progress. A mixture of equal parts of snow, or pounded ice and common salt, will sink the thermometer from 32° to 0°, or the point from which Fahrenheit commenced his thermometric scale, upon the mistaken notion that he had obtained the absolute zero of heat. It is this mixture which is commonly employed for freezing cream. From the rapidity with which salt and ice react upon one another and produce liquefaction, salt is often strewed upon the pavement of the streets when they become incrusted with hardened snow, and it is then easily removed. The thawing of the ice, by the production of a greater degree of cold, might appear paradoxical to those who have not properly considered the steps of the process.

A mixture of three parts of muriate of lime and two parts of snow will sink the thermometer from 32° to — 50°, a degree of cold sufficiently intense to freeze quicksilver. To produce the maximum effect, the salts should be newly crystallized, reduced to a fine powder, and cooled to 32°, and the vessels in which the freezing mixture is made should be very thin. The mixture should also be made as rapidly as possible.

One of the most striking modes of illustrating the absorption of heat by liquefaction, is by the action of metallic bodies alone: if 207 parts of lead, 118 of tin, and 284 of bismuth be melted together, and reduced to a fine state of division by pouring them into water, upon dissolving the alloy in 1617 parts of quicksilver, a thermometer immersed in the mixture will sink from 63 to 14, and water may be frozen by the process.

All liquids remain perfectly fixed at the temperature of their congealing points during the process of liquefaction, or as long as any of the substance remains in the solid form: their temperatures cannot rise, because all the heat to which they may be exposed is absorbed and rendered latent. The use of this point in water for the graduation of thermometers we have already noticed (§ 110).

§ 146. The following is a table of the congealing points of various bodies, including a range of temperature from the boiling of water to the freezing

of mercury, throughout which the law is
tained:

Table XII.—*Of Congealing Points.*

Sulphuric ether	− 46°	Acetic acid	[illegible]
Mercury	− 39	Tallow	[illegible]
Oil of turpentine	+ 14	Wax	[illegible]
Water	− 32	Sulphur	[illegible]
Olive oil	− 36		

The fusing or congealing points of metals higher ranges of the pyrometer are equally and the temperature of melting iron or gold is riable in the heat of the most powerful wind nace, so long as any of the metal remains solid state.

Table XIII.—*Congealing Points of*

Mercury	− 39°	Zinc	[illegible]
Potassium	+ 136	Silver	[illegible]
Sodium	194	Copper	[illegible]
Bismuth, lead and tin alloy	212	Gold	[illegible]
Tin	442	Cast Iron	[illegible]
Bismuth	476	Iron and Platinum	above [illegible]
Lead	612		

§ 147. The quantity of heat absorbed or latent by the fusion of various bodies is not a stant quantity for all, but varies in different this is shown by the following results of the iments of Dr. Irvine:

Table XIV.—*Latent Heat of Liquids.*

Water	140°	Bees' wax	[illegible]
Sulphur	143.7	Zinc	[illegible]
Spermaceti	145	Tin	[illegible]
Lead	162	Bismuth	[illegible]

§ 148. When liquids, on the contrary, pass the solid state, their latent heat becomes water, by careful management, as by exposing an undisturbed atmosphere to a freezing mixture with a little oil floating upon its surface, may be cooled several degrees below its freezing-point without solidifying; but the moment that, by agitation or other means, it is made to congeal, it rises to the temperature of 32°.

If spirit of wine be poured into a saturated solution of sulphate of potassa, the salt is instantly precipitated in the solid form, and the temperature of the liquid rises so as to become sensibly warm to the hand. When water is poured upon quicklime, a great degree of heat, and sometimes ignition, is produced, from the solidification which it undergoes in consequence of chymical combination. In short, congelation is at all times a heating, and liquefaction a cooling process, to all surrounding bodies.

If we pursue the relations of matter and heat under the next change of physical condition, we shall find the same laws maintained in the passage of a body from the state of a liquid to that of a vapour, and in the contrary operation of passing from the aeriform to the liquid condition. There is no more clear and convincing mode of exemplifying the phenomena than by reference to the common still and worm tub. During the whole process of ebullition in the still, when once the liquid has attained its boiling-point, the temperature never rises above that point: notwithstanding the constant action of a strong fire it never varies, but all the heat is absorbed, and fixed by the process of vaporization. The water in the worm-tub, on the contrary, becomes hotter and hotter during the passage of the vapour again into the liquid state, and, unless the cold water were constantly renewed, the process could not be carried on. The vapour, in fact, acts the part of the carrier of the heat, taking it from the fire and delivering it up to the water.

The heat given off by steam during its condensation is now commonly applied to the warming of buildings, and is at once safe, salubrious, and economical.

§ 149. If the process of vaporization had not been thus progressive; if the constitution of a liquid had been such, that, upon reaching a certain temperature, it would have been at once converted into the aeriform state, the boiling of a teakettle would have been a service of imminent danger; the whole volume of water would have at once flashed into steam with explosive violence.

Such a danger is, in fact, incurred upon distilling oil of vitriol, without great caution. The specific heat of the vapour of this acid is very small, and hence, when it begins to boil, sudden explosions of dense vapour rush forth from time to time, and the glass retort is liable to be broken by the concussion.

Every liquid, when of the same degree of purity, and under equal circumstances of atmospheric pressure, has one specific point at which it invariably boils: thus, pure water boils at 212°; spirits of wine, of the specific gravity of .813, at 173°; ether, at 96°, when the pressure of the atmosphere, as indicated by the barometer, is thirty inches: that is to say, at those respective temperatures their several vapours attain an elasticity equal to that of the incumbent atmosphere, and they are enabled by the slightest impulse to act upon the air in mass, and to remove its obstruction to their course.

§ 150. The decrease of the atmospheric pressure enables vapour of low degrees of elasticity to overcome its resistance, and hence liquids boil at lower temperature when it is diminished. Under the receiver of an airpump water may be made to boil at the temperature of 32°: that is to say, the pressure may be reduced till the vapour of water at that temperature, which is of no higher degree of elasticity than would be sufficient to support a column of mercury in the barometer of 0.20 inches, would be sufficient to remove it, but the full amount of latent heat must be absorbed in its passage into the aeriform state.

If some ether be placed under the receiver of the airpump, and an arrangement made by means of a sliding-rod, by which a small flask of water, covered with some bibulous substance, be alternately dipped into it and removed when the exhaustion is made, the ether will boil rapidly, and, absorbing the heat of the water, will cause it speedily to congeal.

Mercury may even be frozen by the same process, by substituting sulphuret of carbon for the ether. The rapid evaporation of water is carried on with the greatest facility under diminished pressure, especially if the steam which is formed be condensed during its formation, so as to remove the resistance of its elasticity. Upon this principle depends an ingenious mode of freezing water in common atmospheric temperatures, devised by the late Sir John Leslie. For this purpose, some substance which rapidly absorbs the vapour of water, such as oil of vitriol (dried basaltic rock, or dried oatmeal will answer the purpose), is placed in a flat dish upon the plate of the airpump; over this is supported upon a glass trivet a capsule of glass, containing a little water, and a delicate thermometer, and the whole is covered with a low glass receiver; when the vacuum is made, a very instructive series of phenomena ensue. The water is speedily seen to boil, or give out large bubbles of steam, and the thermometer begins to fall very rapidly, denoting that the free heat, or heat of temperature, is rapidly absorbed during the process of vaporization. This steam is instantly absorbed by the oil of vitriol, which becomes hot by the evolution of the latent

heat of the steam during its return to the l
state, and in a short time the whole remaind
the water is converted into a cake of ice.(28)

Another beautiful illustration of the same
ciple is afforded by a little apparatus of the lat
Wollaston, which was named by him the *cryopl*
or frost-bearer. It consists of two bulbs of
connected together by a long stem of glass
containing water. The water is boiled in o
the bulbs till the included air is expelled by the
erated steam, through a small aperture in the
bulb, which is then sealed at a lamp; when
the pressure of the included steam is reduc
that due to the temperature of the air: if the e
bulb be now surrounded with a freezing mixtu
snow and salt, its elasticity again falls, and
evaporation takes place from the water in th

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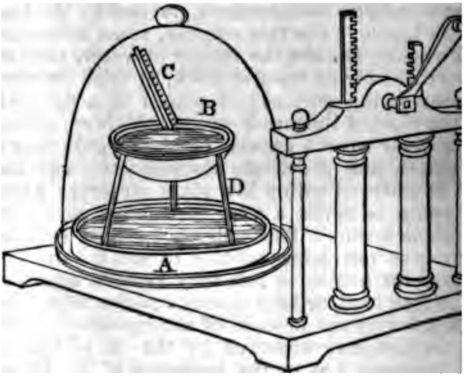
(28) A is the glass dish which contains the acid; D th
supporting the glass capsule, B, three parts filled with
and C the thermometer, to show the progress of refrigera

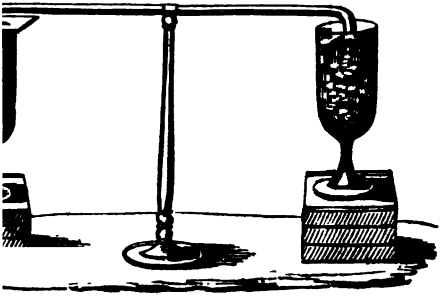


l, which is soon converted into ice by the straction of its heat of temperature.(29)

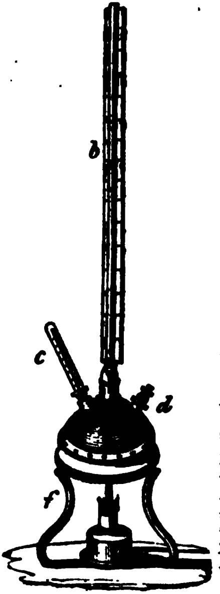
The rapid evaporation of water at low tures, under diminished pressure, has been lvantage of in the arts, in certain processes egetable products are liable to injury from e to high temperatures. Thus the manu- of sugar has been improved in the process Howard, by which the boiling of the sirup ed on in close pans, from which the air is d by means of the airpump: and the prep- of vegetable extracts is effected without any of burning, by Mr. Barry's process, in close from which the air is expelled by steam, the y of which is afterward reduced by cold The distillation of spirits is also effected by means, without the danger of imparting an amatic flavour to the products.

In consequence of the diminished elasticity air in the upper regions of the atmosphere, ing-point of liquids is lower on the tops of ns than at their bases; and water boils at

is figure represents the Cryophorus, arranged for the t, with one of its balls immersed in the freezing mix-



the summit of Mount Blanc, at the te
187°. The late Archdeacon Wollasto
apparatus upon this principle which is
the measurement of heights. It con
curial thermometer, with a very large
into a small portable boiler, which is
by a spirit-lamp. By means of a vern
part of a degree may be read off up
and although such a thermometer wo
follow, and imperfectly indicate cha
spheric temperature, in consequence
quantity of the mercury to be heated, th
of the boiling-point of water easily
being exposed t
ficient time to
effect. He foun
ence of barom
of 0.589 inches
lent to 1° in the
which was clearl
the instrument.



§ 153. It follo
principles which
established, that
sure greater tha
atmosphere, liq
quire a higher t
make them boil;
generate vapou
equivalent to t
If water be enclo
boiler, at the bot
some quicksilv
into which an
ter-tube may be
passing through
ing-box, and the
mometer be im
water through a

ing-box, it may be made to boil. The steam being allowed to escape into the air through an open stopcock, the thermometer, under these circumstances, will indicate the usual temperature of 212°.(30) If the stopcock be then closed, the elastic force of the confined steam will gradually increase; and, reacting upon the surfaces of the water and quicksilver, will raise a column of the latter in the barometer-tube, or gauge, which by its height will measure the elasticity of the rising vapour: as the column ascends, the temperature will augment; and when it attains the height of thirty inches, denoting that the atmospheric pressure is doubled, the thermometer will indicate the temperature of 250.5.

The subject has recently been examined by a commission of the Academy of Sciences at Paris, at the head of which were MM. Dulong and Arago; they obtained the results set down in the following table, by actual experiment, to twenty-five atmospheres, or a pressure of 375 lbs. upon the square inch, and extended it by calculation to fifty atmospheres:

TABLE XV.—*Force and Temperature of Steam.*

Atmos.	Temp.	Atmos.	Temp.	Atmos.	Temp.
1	212°	10	358°.88	19	413°.78
2	250.52	11	366.85	20	418.46
3	275.18	12	374.00	21	422.96
4	293.72	13	380.66	22	427.28
5	307.5	14	386.94	23	431.42
6	320.36	15	392.86	24	435.56
7	331.70	16	398.48	25	439.34
8	341.78	17	403.82	—	——
9	350.78	18	408.92	50	510.60

§ 154. The solvent powers of water are greatly

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(30) In the opposite figure *a* is the strong brass globe, com-
d of two hemispheres, screwed together with flanches; *b* is barometer-tube passing through the steamtight collar; *c* is thermometer, graduated to 400°, and also passing through amtight collar; *d* is a stopcock, and *e* a spirit-lamp. The e is supported upon the brass stand *f*.

increased by the elevation of temperature, i
may be communicated to it by pressure; an
property was turned to economical account i
pin's digester, which consists of a boiler, fit
means of wedges with a close cover, in whic
safety-valve, which, being loaded with weight
yields when the internal pressure exceeds a c
amount. This apparatus has recently been
ployed for the extraction, upon a large scale, o
gelatinous and albuminous matter which abou
bones, and the product has been applied to th
poses of nutrition. As the temperature of ste
always that of the liquid producing it, and m
accurately regulated by the degree of pre
high-pressure steam is often applied with gre
vantage when a steady heat may be required.

§ 155. The following is a table of the bo
points of several liquids, under a mean baro
pressure of 30 inches:

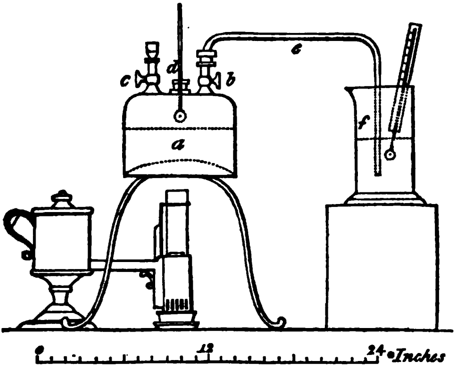
TABLE XVI.—*Of the Boiling-points of Liqu*

	Fahren.		
Ether, sp. gr. 0.736, at 48°	100	Water . . .	
Sulphuret of Carbon	113	Oil of Turpentine .	
Alcohol, sp. gravity 0.813	173.5	Sulph. acid, sp. gr. 1.8	
Nitric acid, sp. gr. 1.500	210	Mercury . . .	

§ 156. Having seen that a large quantity of
is absorbed or becomes latent in the passage
liquid to the aeriform state, and is again give
by its recondensation, it becomes an intere
subject of inquiry to ascertain the quantity w
thus enters into combination. Dr. Black app
matively determined this for water by a very si
experiment. He placed two cylindrical flat
tomed vessels of tin-plate of similar dimens
containing equal measures of water at 54°, upo
iron plate which was kept heated. He noted
in four minutes the water began to boil, an
twenty minutes the whole had evaporated. In

minutes, therefore, the water had received an augmentation of temperature of 162°, or 40 1-2° in each minute, by which it was carried up to its point of ebullition; calculating that the heat continued to enter the water at the same rate during the whole time of boiling away, he concluded that 810° (or 40 1-2 × 20) was carried off, and became latent in the steam. Dr. Henry contrived an apparatus by which the experiment may be made with much greater precision. It consists of a close boiler, with a thermometer, from which a bent tube proceeds, which may be made to dip into a measured quantity of water in another vessel, and in which the steam may be condensed.(31) Supposing the latent heat of steam to be 900°, a quarter of a pint of water raised to steam in the boiler would, by

(31) *a* is the copper boiler in which the measure of water is placed; *d* is a thermometer plunged into the same; *c* is a stopcock; *b* is another stopcock, opening a communication with the bent tube, *e f*, plunged beneath the surface of the measured water in another vessel, the temperature of which is to be raised by the condensation of the steam.



recondensation into water, raise the temperature o an equal quantity in the condenser 900°, if it wer possible, or, what is equivalent to this, ten quarter pints, 90°, which result is easily obtained. On gallon of water, converted into steam at the ordi nary pressure of the atmosphere, will, by conden sation, raise five gallons and a half of ice-cold wate to the boiling-point. The best and most carefu experiments agree in fixing the latent heat of stea between 900° and 1000°.

§ 157. The latent heat of different vapours differs as we have found the heat of fluidity to differ, i various liquids. The following is a table of th latent heat of steam and some other vapours, b Dr. Ure:

TABLE XVII.—*Latent Heat of Vapours.*

Vapour of Water, at 212°	. .	1000°
"	Alcohol	457
"	Ether	312.9
"	Oil of Turpentine . .	183.8
"	Nitric Acid . . .	550
"	Ammonia . . .	865.9
"	Vinegar	903

§ 158. The density of steam (*i. e.*, the weight [illegible] a given volume) increases directly as its [illegible] force, upon the same principle that the density [illegible] air increases with the pressure to which it is [illegible] posed; and the same weight of steam [illegible] whatever its density may be, the same [illegible] heat; its latent heat being increased in [illegible] as its sensible heat is diminished or absorbed. [illegible] principle admits of explanation by the [illegible] supposition: Let us imagine that, in a cylinder [illegible] nished with a piston, we have a certain [illegible] steam, and that it is suddenly compressed [illegible] stroke of the piston into half its bulk, without [illegible] reduced to the liquid state; it would acquire [illegible] elasticity, and its temperature would be [illegible] If we either suppose the cylinder incapable of [illegible] heat, or take the moment instantly follow- compression, before any heat has had time pe, it must be evident that the sensible and eat together, before the compression, are ly equal to the sensible and latent heat after npression; but in the dense steam the sen- eat is increased, and the latent heat dimin- y equal quantities. Reversing this imaginary ent, if we suppose only half the cylinder to steam at 212°, and the piston to be suddenly so as to double its volume, the density, of will be reduced to half, and its temperature l, but its sensible and latent heat together nain unchanged.

fact was long ago experimentally determined Watt; but the experiments of MM. Clement sormes present us with the following more e results:

rtain weight of steam at 212°, ndensed at 32°, gives out .	180°	Sensible heat.
	950	Latent
	1130	
same weight at 250° . .	218°	Sensible.
	912	Latent.
	1130	
same weight at 100° . .	68°	Sensible.
	1062	Latent.
	1130	

espretz ascertained that the same law holds ith other vapours.

. When water is converted into steam, it es a much greater expansion of volume y other liquid hitherto examined. It ex- ight times as much as sulphuric ether, and three times and a half as much as alcohol. he vapours of ether and alcohol are heavier than that of water, although the former, i liquid states, are lighter than the latter. T crease of volume which certain of the com liquids undergo, when converted into vapour ordinary elasticity of the air, is set down following table:

TABLE XVIII.—*Of the Increase of Volume Vaporization.*

1 cubic foot of water = 1689 cubic feet of vap
1 cubic foot of alcohol = 493.5 "
1 cubic foot of ether = 212.18 "
1 cubic foot of spirits of turpentine = 192.15 "

§ 160. It has sometimes been hastily con from the less latent and sensible heat of the v of alcohol, ether, and turpentine, that they mi used advantageously as generators of mech force, instead of the steam of water; but i case their comparatively small expansion ha overlooked. Their cost in fuel would be p tionate to the latent heat of equal volumes.

L
A cubic foot of water yields 1700 cubic ft. . =

A cubic foot of alcohol yields 493 cubic ft. = 457°
And 493 cubic ft. : 457 : : 1700 : . . .

A cubic foot of ether yields 212 cubic ft. = 312°
And 212 : 312 : : 1700 : . . .

A cubic foot of spirits of turpentine yields
192 cubic ft. . . . . . . = 183°
And 192 : 183 : : 1700 . . . .

So that if alcohol, ether, and spirits of turp could be procured for nothing, it would b much cheaper to employ water for the gene of steam for the purpose of obtaining mech power.

§ 161. A remarkable fact has been observ specting steam of great elasticity, viz., that, suffered to escape suddenly from a cock o aperture in the boiler, the hand may be held close to the orifice from which it is rushing violently, without being scalded by it, though common experience has taught most persons that steam of ordinary density scalds severely under similar circumstances. A part of this diminution of temperature may be owing to the sudden expansion which the steam undergoes when released from confinement, and which probably absorbs a portion of the heat evolved during its return to the liquid state; but its chief cause is its sudden and forcible mixture with cold air at its first rush. A large quantity of air is thus violently drawn along with it in its course. Dr. Young long ago proved that a stream of air, or vapour, or smoke, issuing gradually into the atmosphere, penetrates farther in an unbroken column than a stream issuing with violence; in the latter case, the elastic fluids become immediately mixed, from the violent action and reaction which takes place.

The working of the steam-engine depends upon the elastic force of steam, communicated by heat, and the instantaneous annihilation of that force by cold. The first principles of this machine are prettily illustrated by the simple apparatus of Dr. Wollaston, which we have already described (§ 65).

§ 162. Vapour, however, is not only formed from liquids at their boiling-points under the pressure of the air, and at lower temperatures when that pressure is lessened or removed, but is constantly rising from their surfaces in the progress of spontaneous evaporation. Common experience has taught every one that water evaporates into the atmosphere at all temperatures, however low, and the same process takes place with other liquids. Dr. Faraday has, indeed, shown that vapour rises from mercury at common temperatures, at least from 60° upward, although its elasticity is so very low as not sensibly to depress the height of the mercurial column in the barometer. He placed some quicksilver in the bottom of a glass vial, to the stopper of which he attached a piece of gold leaf, which speedily became white, from the amalgamation of the gold with the vapour which rose. If five barometers be prepared for the purpose, and a little water be thrown up into the air-free space of the first, a little alcohol into the second, ether into the third, and sulphuret of carbon into the fourth, each column will be depressed by the elastic force of the vapour of each liquid at the existing temperature of the air; and the amount of the depression may be determined by comparison with the column of the fifth barometer, into the vacuum of which no liquid has been introduced. The tension of the vapours increases with the temperature, provided the whole space in which they are diffused be heated to an equal degree; but by heating the liquids, by the warmth of the hand or otherwise, they may be able to boil, without increasing the elasticity of the vapours, which are condensed as soon as formed. The following table exhibits the force and the weight of a cubic foot of steam at different temperatures:

TABLE XIX.—*Of the Force and Weight of Steam at different Temperatures.*

Temperatures.	Inches of Mercury.	Weight of Cubic Foot.
		Grains.
32°	0.216	2.53
40	0.280	3.23
50	0.400	4.53
60	0.560	6.22
70	0.770	8.39
80	1.060	11.33
90	1.430	15.00
212	30.000	257.218

§ 163. Evaporation to the same degree takes place under the pressure of the atmosphere, but is entirely confined to the surface of the liquid, and is therefore proportional to the surface. If the surface of water be covered with oil, its evaporation is altogether stopped. In some places on the south coast of England, as in the Isle of Weight, sea-salt is obtained by allowing sea-water to evaporate spontaneously in large tanks; the process is afterward completed by boiling down the brine which has thus been concentrated. In parts of Germany the same process is carried on with saline springs; but the evaporating surface is largely increased by pumping up the water to a great height, and then suffering it to percolate through immense stacks of brushwood fagots. Evaporation does not proceed so rapidly when the air is still as when it is agitated by a brisk wind; and the more rapid the current of air, the more rapidly, *cæteris paribus*, does the water disappear. When the air is calm, the vapour, as it forms, rises perpendicularly, but rests upon the surface of the water; and it is the pressure of its own vapour upon the surface of a liquid, and not the pressure of the gaseous atmosphere, which puts a stop to the process.

§ 164. The rate of evaporation increases also with the temperature, and the elastic force of the vapour given off increases in a geometrical progression with equal increments of sensible heat. The following is a table of the force of vapour at different temperatures, and the rate of evaporation per minute from a circular surface six inches in diameter, according to the experiments of Dr. Dalton:

TABLE XX.—*Of the Force of Vapour and Rate of Evaporation per Minute.*

Temp. Fahr.	Force.	Calm.	Breeze.	High Wind.
	Ins. of Merc.	Grs.	Grs.	Grs.
212°	30.000	120.00	154.00	189.00
85	1.235	4.92	6.49	8.04
75	0.906	3.65	4.68	5.72
65	0.657	2.62	3.37	4.12
55	0.476	1.90	2.43	2.98
45	0.340	1.36	1.75	2.13
35	0·240	0.95	1.22	1.49
25	0.170	0.67	0.86	1.05

These amounts ef evaporation are, however, only maintained when the incumbent air is perfectly dry, when no vapour pre-exists in it. If vapour be already present, as is always the case in the atmosphere of this climate, the quantity capable of evaporating at any given temperature will be the quantity indicated in the table, diminished by the quantity already incumbent upon the water.

§ 165. Various instruments have been invented for measuring the quantity of vapour existing in the atmosphere, or its relative degrees of dampness and dryness: they have been denominated hygroscopes and hygrometers.

M. Le Roi, and afterward Dr. Dalton, adopted a very simple and accurate method of determining the elastic force of vapour at any time existing in the air. It is founded upon the well-known property that the moisture of the atmosphere will condense itself upon the surface of a colder body in contact with it.

When a bottle of wine is brought from a cool cellar, or a glass on a summer's day is filled with water fresh drawn from a deep well, it becomes dewed upon the surface. By pouring such cool water into another glass, then carefully drying the surface of the first, and returning it and repeating the operation as often as may be necessary, the water becomes slowly warmer, and Dr. Dalton carefully marked with a delicate thermometer the temperature at which the dew just ceased to form, and this he appropriately denominated the *dew-point*. It is, in fact, the temperature of water which would yield vapour of the precise elasticity of that upon which the observation is made; and all the relations of such vapour being known, the observation is applicable, with certainty, to the determination of every question that can be proposed concerning it. Even in winter-time, or in very dry situations, a sufficient reduction of temperature may be produced in the liquid by the frigorific effects of the solution of salts, to produce the effect of precipitation. The observation is rendered more precise by using small bright metallic vessels, upon the cool surface of which the dew is most visible.

§ 166. To facilitate the observation of the dew-point, the author some years ago contrived a hygrometer, which has been extensively used in every part of the globe with certainty and advantage.* It consists of two small glass bulbs, connected together by a glass tube, bent twice at right angles in the manner of the cryophorus (fig. 29). A very delicate thermometer is enclosed in one bulb, which, being filled with ether, is heated till the vapour issues with full force from an aperture in the other, which is then hermetically closed. If the operation has been well performed, upon taking the bulb which contains the liquid in the hand, after it has cooled to the temperature of the surrounding air, it will boil, *i. e.*, vapour will be abundantly generated by the heat of the hand, which will be simultaneously condensed in the other cool bulb. The empty bulb is then to be covered with a piece of fine muslin, and, when ether is dropped upon it, the volatile liquid will evaporate and cool the bulb. This exterior evaporation will caus sation of the vapour of the internal vapou ether included in the farther bulb will im begin to evaporate, and cool its exterio The fall of the interior thermometer will degree of the falling temperature, which noted as the dew-point, at the moment th ring of dew, just coincident with the surf liquid, forms upon the glass. The temper still continue to fall some degrees, but a tion of the observation may be obtaine serving the thermometer when it again rise, and noting the degree at which th dew again disappears. The two observa dom differ more than a degree or two, and may be depended upon as accurate: for t if any, must lie in opposite directions.(32)

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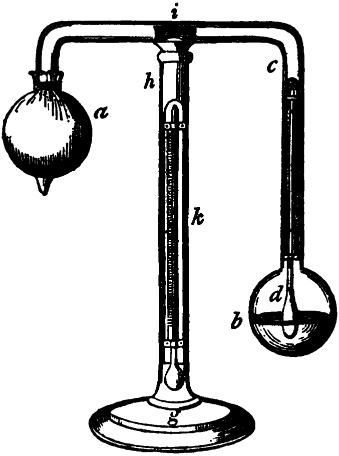
* DANIELL's Meteorological Essays, p. 139.



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(32) T
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§ 167. By means of the dew-point accurately ascertained, many points of the utmost interest to chymical and meteorological science may be determined.

By mere inspection of tables properly constructed, we can at once determine the elasticity and density of the aqueous vapour; its weight in a cubic foot of the air; the degrees of dryness either upon the thermometric or the hygrometric scale, and the rate of evaporation; when the air is saturated, the precipitation is instantaneous, *i. e.*, the dew-point coincides with the temperature of the air. In this country, the degrees of dryness measured in thermometric degrees seldom reaches 30°, that is to say, the dew-point is seldom 30° below the temperature of the air; but in the Deccan, with a temperature of 90°, the dew-point has been seen as low as 29°, making the dryness 61°.

The more accurate mode, however, of expressing the moisture of the air from an observation of the temperature and dew-point, is by the quotient of the division of the elasticity of vapours at the real atmospheric temperature, by the elasticity at the temperature of the dew-point: for, calling the term of saturation 1000, as the elasticity of vapour at the temperature of the air is to the elasticity of vapour at the temperature of the dew-point, so is the term of saturation to the observed degree of moisture. Thus, with regard to the observation in the Deccan,

$$1.430 : 0.194 :: 1000 : 135.$$

The fourth term is the degree of moisture on the hygrometric scale.

§ 168. There is another method of estimating the opposite states of dryness and moisture, and that is by measuring the degree of cold produced by evaporation. Water does not evaporate at all when the air is saturated with moisture, *i. e.*, when the incumbent steam is of the full force of that which is due to the temperature; and the freedom with w the process proceeds at other times is in propo to the dryness of the air, that is to say, to the di ence of the force of the existing vapour and which might exist at the temperature of the Dr. Hutton was the first to propose the observ of the depression of temperature caused by we the bulb of a thermometer as a measure of the of evaporation, and, consequently, of dryness. John Leslie afterward adapted a differential mometer to the purpose: his hygrometer cons of a delicate air-thermometer, one of the bul which was covered with muslin, and was kept tinually wet by the dropping of water from a v by its side. A scale was adapted to it, to divid space which the liquid was depressed by ext dryness, into 1000 equal parts.

§ 169. This property with which water has endued, of spontaneous combustion at all tem tures, even below its freezing-point, is one o most important in the whole economy of na for upon it the growth of plants and the exist of all living creatures upon the earth depends. vapour, thus rising continually, not merely fro surface of the sea, lakes, and rivers, but also the land in different states of moisture, is again densed in the upper regions of the atmosphere falls in the state of hail, rain, or snow. Rest to the liquid state, it penetrates into the stra the earth, and makes its way out again in spri these, collecting together, constitute rivers, w under the force of gravitation, descend to the and complete the grand process of distillation circulation.

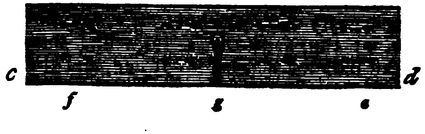
The ultimate processes of evaporation and densation tend also to that distribution of heat the globe which we have already noticed as so es tial to the well-being of the organic creation. is thus carried in its latent state to the upper re

the atmosphere, and is there given out in its free
te by the condensation of the steam; and upon
s silent and never interrupted process mainly de-
nd the fluctuations of the aerial ocean, which tend
greatly to its salubrity, and which produce the
served variations of the barometer.

§ 170. The cause of these perpetual oscillations
s long been a subject of investigation with phi-
ophers, and many erroneous explanations have
en given of the phenomena. The problem, in all
generality, is difficult and complicated, and may
rcely, perhaps, be deemed to belong to the de-
rtment of chymistry. Without, however, going
o the details which belong to meteorological sci-
ce, it is desirable that an accurate notion should
formed of the true causes of the barometric
anges, to which such constant reference must be
de in many of the most important chymical op-
tions. It has already been pointed out (§ 135),
t, owing to the unequal distribution of heat upon
surface of the globe, and the gradual decrease
temperature from the equator to the poles, the
stic fluids of the atmosphere must perpetually
culate between the colder and the hotter points;
wing from the former to the latter on the surface
the earth, and returning from the latter to the
mer in upper opposite currents. Now it is clear
t, if such be the fact, the barometer weighs the
ssure of these two combined currents at any
en point; and so long as they balance one an-
her, that is to say, so long as an equal quantity
air is brought by one stream to the base of the
pendicular column, to that which is carried off
the opposite from its summit, so long will their
mbined pressure be unchanged. But should any
use, partially acting, check the course of one,
thout, at the same time, impeding that of the
ner, the balance will be destroyed, and the barom-
r, by its rise or fall, will mark the amount of the

disturbance. Owing to various causes, but chiefly to the equal distribution of water and land, the course of the winds is by no means so regular as assumed above; but this grand system of compensating currents certainly results, although masked by circumstances in particular regions; most of these, however, give rise to minor systems of compensating currents, to which, as concerns the barometer, the same remarks will apply. Any one, indeed, may convince himself that such systems prevail in the atmosphere, by watching the progress of the clouds; and in this way he will often be able to detect more than two such currents existing together. Now, while he is observing their courses, let him for a moment suppose that the barometer is perfectly stationary, and then let him imagine one of the streams of air before him suddenly checked; the others will continue to flow on for a time in their primary direction from their inertia, and in obedience to their original impulse, and the barometer, he will conceive, must fall, because more air is carried off above it than is compensated by the current which originally maintained the balance; and, as a deficiency may be thus produced in one part of the atmosphere, an equivalent accumulation must, at the same time, result in some other part.(33)

(33) Let *a b c d*, in the annexed diagram, represent two currents flowing in the opposite directions indicated by the darts: a barometer placed in the lower at *g*, will support the pressure



A cause, quite competent to produce these partial effects, exists in the atmosphere of steam mingled with the atmosphere of permanent gases, and which is constantly rising from the surface of the earth, varying in force with the temperature of the waters from which it emanates. This vapour rises unchanged and transparent, till, in the gradual decreasing temperature of the air, it arrives in the upper regions at a degree of cold by which it is condensed, and, becoming visible, assumes the form of clouds. In the act of condensation, however, an immense quantity of heat is set free, which was previously combined with the steam in the latent form; and this, acting upon the surrounding air, whose capacity for heat is small, expands it, and gives an additional but unequal impulse to the current in which the process takes place. The clouds, again, are themselves subject to a new evaporation, and the vapour is carried to still higher regions, where another precipitation takes place; till, at length, large masses of the atmosphere have the natural progression of their temperature changed and their currents altered, or, perhaps, reversed. The increased temperature of the air is accompanied by a great increase in the force and quantity of the steam, the final precipitation of which takes place in the form of rain, and the atmosphere returns to its mean state through the influence of winds, which restore the original balance. The order of the phenomena corresponds with the facts that the barometer is most steady when the weather is clear, and fluctuates most with clouds and rain; and also explains the reason why, in the

of both, and remain without oscillating so long as the two currents remain unchanged. But if a partial expansion, affecting the upper current alone, should urge it forward on its course on one side and check it on the other, an accumulation of the nature of a wave would take place at *b*, and a corresponding deficiency at *a*, as indicated by the curve *a b*, and would be accompanied by a rise of the thermometer at *g*, and a corresponding fall at *f*.

greater disturbances of the aerial ocean, local deficiencies of the elastic fluid are restored by winds whose force is generally proportioned to the vacuum which they supply.*

§ 171. Aerial fluids are commonly distinguished into two classes, viz., vapours and gases; but the experiments of Dr. Faraday have nearly annihilated the distinction, and proved that the difference is one of degree only, and not of constitution. In vapours, strictly so called, such as the steam of water, the latent heat is retained in combination with very little force; for it abandons the water when the vapour is exposed to a lower temperature; but in gases the heat of composition is retained very forcibly, and no diminution of temperature that has ever been produced can separate it from some of them. Dr. Faraday has, however, succeeded in reducing to a liquid state many of those substances which till very recently were considered as permanently elastic fluids. His method is to generate them under strong pressure, by confining the substances from which the gases are evolved in strong glass tubes, in which their elasticity is allowed to increase till it forces their particles within the verge of cohesive attraction, when they assume the form of liquids. This operation he farther assists by the application of cold mixtures to the exterior of one extremity of the tube. When thus produced, they continue liquid while the pressure is kept up, but on removing the pressure, instantly pass into the gaseous state. The same condensation may also be produced by mechanical force, and considerable quantities of carbonic acid have been thus reduced to the liquid state by Mr. Brunel, with the view of applying its expansive power as a mechanical agent The cold produced by the sudden evaporation of these liquids is so great as actually to preserve some of the substances in their liquid state under the mere pressure of the air, and carbonic acid has been even frozen by the cold produced by its own spontaneous evaporation. Mr. Brunel was the first to observe this fact, and the loss of elastic force thus occasioned was, it is believed, the cause of giving up the attempt to construct a gas-engine.

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* DANIELL's Meteorological Essays, p. 559.

§ 172. More recently, some very interesting results have been obtained by M. Thilorier, who has ascertained that the expansion of liquid carbonic acid for every degree of heat exceeds that of the acid in the gaseous state even by four times, and the pressure of the vapour from 32° of Fahrenheit to 86°, rises from 36 to 73 atmospheres.

A jet of liquid carbonic acid sinks the thermometer to 130° Fahrenheit below 0°.

It has little capacity for heat, and from its want of conducting power, its cooling effects alone do not correspond with the depression; but when mixed with vapour of ether, M. Thilorier succeeded in forming a cold blowpipe, which froze 800 grains of mercury in a few seconds.

§ 173. A gas, then, may be regarded as the vapour of a liquid whose elasticity, at ordinary atmospheric temperatures, is such that it is not only equivalent to the pressure of the ordinary atmosphere, but to that of many atmospheres, and which would therefore boil under the pressure of many atmospheres, and cannot consequently be preserved except under artificial pressure. The pressure required to condense the several gases is recorded in the following table:

TABLE XXI.—*Liquefaction of Gases.*

	Pressure in Atmospheres.	Temperature, Fahrenheit.
Sulphurous acid	2	45°
Chlorine	4	60
Cyanogen	4	60
Ammonia	6½	50
Sulphuretted hydrogen	17	50
Carbonic acid	36	32
Muriatic acid	40	50
Nitrous oxyde	50	45

Many gases have hitherto resisted the utmost degree of compression and cold to which it has been practicable to expose them, but from the generality of the law its universality is a legitimate deduction; and geologists are justified in speculating upon the existence of the atmospheric gases themselves in a state of liquidity, in the fathomless depths of the earth, under the enormous pressures to which they must there be necessarily exposed.

Some gases, however, though incoercible, or requiring very high degrees of force to coerce them, by mechanical means and cold, instantly yield to the force of heterogeneous adhesion, and, as they become dissolved in water, give out their latent heat. Thus, if a current of muriatic acid gas be passed into water, it will be rapidly absorbed, and the temperature of the solution will rise considerably.

§ 174. We have seen that water and other liquids gradually expand in volume with increase of temperature, and that, on the other hand, steam and other vapours rapidly increase in density, as the pressure and temperature to which they are exposed augments; whence it is clear that, at some particular assignable point, the liquid and elastic states must coincide, and there must be a limit beyond which a liquid, notwithstanding the pressure, ought to be wholly volatilized, or become gaseous, provided sufficient space be allowed for the expansion. M. Cagniard de la Tour, reasoning upon the general facts, was led to make some interesting experiments upon the subject. A strong glass tube, containing alcohol equal in bulk to about two fifths of its capacity, being hermetically sealed and carefully heated, the alcohol was observed to expand, till, after having attained nearly double its original volume, it suddenly disappeared, being converted into vapour so transparent that the tube appeared to be completely empty. Allowing it to cool, the alcohol was again suddenly converted into the full volume of liquid. When the proportion of alcohol to the capacity of the tube was increased, the consequence was the bursting of the tube. Similar results were obtained with naptha and ether, the latter requiring less space than the former for assuming the complete elastic state, and the naptha less space than alcohol. The ether became gaseous at a temperature of 320°, and exerted a pressure of 38 atmospheres; alcohol at 404 1-2°, under a pressure of 129 atmospheres.

Upon trying the experiment with water, the glass tube broke from its solvent power at the high temperature: but when this action was prevented by the addition of a little carbonate of soda to the liquid, it became gaseous in a space four times its volume at the temperature at which zinc melts.

§ 175. We have hitherto considered heat as inseparable from matter, differing, however, from other forms in its slow progression among its particles; tending, indeed, to an equilibrium, but still capable of existing in various degrees of intensity in different parts of the same mass. Differing, again, in the latent and apparently inactive state in which it becomes stored up in various forms of matter, and from which, though lost for the time to our sensation and our instruments, it may be set free in full measure and proportion.

We have now to contemplate this subtle agent detaching itself from matter, and projecting itself through space and through various kinds of matter with a velocity almost inconceivable.

We recognise heat in this state from the effects of a fire, or a heated body, at a distance. The warmth which we feel, or the expansion which we may observe under such circumstances, cannot be communicated by any material particles; for we may so contrive the experiment that the air, the only form of matter which intermixes, may flow towards the source of the heat.

It is also by this new property of *radiation* that heat tends to that state of equilibrium which, upon a former occasion, we found to be partially established by the processes of conduction and convection.

§ 176. The intensity of radiant heat, like that of gravitation, and for the same reason, decreases as the square of the distance from the source of the rays: thus, if a thermometer, protected from the influence of all disturbing causes, be observed to rise a certain number of degrees at one inch distance from a heated surface, it will indicate four times less heat at two inches; nine times less at three inches; and sixteen times less at four inches.

§ 177. The primary law of reflexion, at an angle equal to the angle of incidence, is also easily recognised by holding a bright metallic plate before a common fire; the rays of heat may then be turned in any direction, according to this law, and tested by our sensation; when we see the image of the fire in the mirror, we also feel its heat.

If we fix two concave metallic mirrors at a distance apart of about ten or fifteen feet, with their axes in the same line, and with their faces parallel and opposed to each other, upon placing a thermometer in the focus of one, at the distance of half the radius from one of them, it will be found sensible to the effects of a heated body placed at the same distance from the other. These points are called the *foci* of the mirrors. It is easy to assure ourselves that the effect is owing to reflexion, and not to the direct radiation of the heated body, by removing the thermometer out of the focus, and approaching it towards the source of heat, when it will be found to fall; or, the same return to its original state may be produced by placing a screen between the thermometer and its own mirror, when the reflected rays will be cut off, although the direct communication with the radiating body will still be open. In the same way, when a red-hot iron ball is placed in one focus, a piece of paper will be scorched in the other; and gunpowder and phosphorus may be inflamed, even when the temperature of the ball is below ignition.(34)

The heated body placed in one of the foci of these conjugate mirrors throws off its rays in all directions, and those which strike upon the surface of the nearest mirror are reflected in a parallel direction upon the surface of the second mirror, where they undergo a second reflexion, and are made to converge at the second focus, and there act with their concentrated energy.

§ 178. Reflexion from the concave surface of a hollow cone also causes rays of light or heat to converge to a focus, and those who have not the command of conjugate mirrors, such as have been just described, may easily verify the above results simply by a sheet of gilt paper, rolled up in the form of a truncated cone, with the metallic surface inward. If a hot ball be placed at the large ex-

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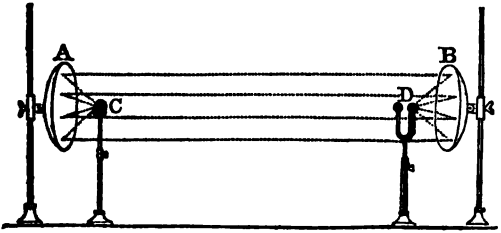
(34) The annexed figure shows the disposition of the apparatus. A and B are the two polished metallic mirrors. The hot iron ball is placed in the focus, C, of the mirror, A, towards which it radiates its heat. The diverging rays are reflected in a parallel direction upon B, by a second reflection from which they are rendered convergent, and fall upon the thermometer, D, placed in the focus to receive them.



tremity of this cone the radiant heat will be reflected to a focus beyond the smaller end, and phosphorus, &c., may be fired.

§ 179. Bright metallic bodies being the best reflectors of heat in the experiments above described, the temperature of the mirrors is not appreciably raised; but if their surfaces be dulled, as by coating them with lampblack, the rays are absorbed by the mirror which is the nearest to the heated body; it becomes hot, and a small and almost inappreciable quantity is transmitted to the second mirror. Bodies, however, which thus absorb radiant heat, throw it off again by a secondary radiation, and scatter it in every direction as from [illegible] centre; and it has been ascertained, by the beautiful experiments of Sir John Leslie, that the best absorbitants of heat are the best radiators.

Heat, propagated by regular reflexion, loses [illegible] of its intensity by increasing the distance which [illegible] has to traverse, except a minute quantity which [illegible] due to the absorption of the medium through which it passes; but, when propagated by secondary radiations, it decreases directly as the square of the [illegible]tance. Two portions, therefore, under these different circumstances, may easily be distinguished [illegible] each other by these different properties.

§ 180. These properties, as well as that of reflexion, depend entirely upon the surfaces of bodies. Sir J. Leslie obtained most of his results with [illegible] simple apparatus of a cubic tin cannister, which [illegible] heated by filling it with boiling water, and [illegible] by coating three of the sides with different substances, he compared their several effects upon a [illegible]cate thermometer, placed at the same distance from each with that of the fourth side, which [illegible] left in its bright and polished state. By these means he found that, taking the quantity of [illegible] radiated by lampblack as 100, the radiating power of a surface covered with glue was 80, and of clear metal 12. The following table was also constructed from Professor Leslie's experiments:

TABLE XXII.—*Radiating Powers.*

Lampblack	100	Tarnished lead	45
Sealing-wax	95	Clean lead	19
Writing paper	98	Polished iron	15
Crown glass	90	Tin Gold Silver Copper } polished	12
China ink	88		
Red lead	80		
Plumbago	75		

He also found that the direction of the lines by which the surface was roughened had a considerable effect upon the result. He scratched a bright metallic surface with a number of lines in one direction, and found the force of radiation increased: he then scratched a similar surface with the same number of lines, half of which crossed the other at ight angles, and obtained a still greater effect. The power of projection seemed to depend upon he number of points produced.

§ 181. M. Melloni has lately ascertained, by experiment, that these differences in metallic bodies do not arise from differences in the state of their surfaces, but from changes in their densities. To determine this, it is necessary to make the observaions with metals which are not easily oxydizable, for the thin coat of oxyde which forms upon tin, or zinc, or brass, is known to radiate much better than he metals themselves. He formed two vessels of pure silver, one of well-hammered plate, and the other of cast metal slowly cooled. He polished one side of each very highly, and the other he scratched with emery paper in one direction only, and, filling them both with hot water, he found the following difference:

10°	For the polished face of the hammered metal.	13°.7	For the polished face of the cast metal.
18°	For the scratched face of the same.	11°.3	For the scratched face of the same.

Comparing these results, it will be found: 1st. That in the case of the polished surfaces, the cast metal radiated nearly 1-3d more than the forged; showing the superiority of the lesser density; 2dly. That in the case of the scratched surfaces, not only does the hammered metal show an augmentation of radiant power of 4-5ths, but the cast metal a diminution of nearly 1-5th.

The latter unexpected effect arises, according to M. Melloni, from the compression of the soft surface of the cast metal by the action of the hard emery.

§ 182. The relation of the powers of reflexion, absorption, and radiation, and the equality of the two latter in similar surfaces, is shown by an experiment of Dr. Ritchie. He placed a hollow metallic vessel, filled with hot water, between the two metallic discs of an air-thermometer. The surface of one disc was bright and polished, and of the other covered with lampblack. One of the surfaces of the heated vessel was also bright and polished, and the opposite surface similarly blackened. When the apparatus was so arranged that a black was opposed to a metallic surface, no effect was produced upon the liquid of the thermometer; but when the blackened surface of the heated vessel was opposed to the blackened disc, the expansion of the air indicated a strong transmission of heat. In the first position, the good radiating surface of the heated vessel was opposed to the good reflecting disc of the thermometer, and its bad radiating surface to the good absorbent surface, and the actions were exactly balanced: but in the second position, the good radiating surface was opposed to the good receptive surface, and the two bright metallic surfaces to each other, so that everything favoured the transmission of heat on one side, and stopped it on the other side, and the liquid of the thermometer instantly indicated the inequality.

§ 183. These principles may be readily illustrated by easy experiments or by the results of common experience. If we take two equal tin vessels, brighten the surface of one and blacken the other, we shall find, upon filling them with hot water, that the water in the blackened vessel will cool much faster than that in the bright vessel. The water in a bright silver teapot will retain heat much longer than water of the same temperature in one of earthenware; and hence the superiority of the one over the other for preparing the infusion. The furniture of the kitchen will also afford abundant apparatus for illustrating the principles of radiation, absorption, and reflection, and their economical applications. If the bottom of the kettle be bright, we shall scarcely be able to boil the water which it contains; but, at the moment it becomes covered with soot, the heat freely passes into it. If the whole of its surface be blackened, the water will soon cool when removed from the fire, and it is in its most efficient state when its sides and top are bright, and its bottom coated. By the meat-screen and the Dutch oven the radiant heat of the fire is reflected, and concentrated upon the operations which are carried on behind them; and innumerable other instances might be adduced in which experience and observation had probably long anticipated the conclusions of experiment and science.

Pipes for the conveyance of hot water or steam should be kept perfectly bright and polished; while at those parts where they are destined to give out the heat to the surrounding atmosphere, they should be roughened, or coated with some good radiating substance. By attending to such circumstances, which might to the uninformed appear trifling and unimportant, the consumption of fuel in the steam-engine itself has been greatly economized.

The thinnest coating of gold leaf covering the finger, will enable a person to approach it within a very small distance of a red-hot iron or other incandescent body; while, if unprotected, it would be burned at ten times the distance. And the same reflecting power may be rendered visible by gilding some letters upon a sheet of paper, and holding a red-hot iron over them, when the uncovered intervals will be scorched, but the letters themselves will be untouched and conspicuous.

§ 184. The radiation of heat is one of the most important processes in the economy of nature, and it is one of the means by which equilibrium of temperature is brought about. Not only does heat travel from a hot to a cold body by the processes of conduction and convection, which we have before examined, but it is projected from the one and absorbed by the other, at a rate dependant upon the state of the surfaces of the two. In every assemblage or system of bodies, as, for instance, the various objects in a room, there is a tendency in each to radiate its heat; which, if met by an equal force or exchange in others, or in the walls of the apartment, is balanced or restrained; but if any inequality exist in the system, the projection takes place towards the weaker point till the balance is restored by absorption.

The same radiation takes place upon a large scale from all the substances upon the surface of the earth towards the regions of space; which, if not met and counteracted by the radiation from the sun, would soon annihilate all organic being by the rigours of an eternal frost.

§ 185. We may easily obtain evidence of this tendency by placing in the focus of a concave metallic mirror the bulb of a thermometer, covered with some good radiating substance, as the short white fibres of wool or cotton. By turning this apparatus towards the clear sky, the thermometer will fall several degrees. It is protected by its position from the radiation of surrounding objects, and its own radiant heat is projected towards the clear space, or, falling upon the concave surface of the mirror, is reflected in parallel lines in the same direction. This effect is produced even while the sun is above the horizon, provided the mirror be turned from the direct rays of that luminary; and at night a depression of seventeen degrees below the temperature of the air and surrounding objects may commonly be produced. Perfect stillness of the atmosphere is necessary, and perfect transparency also, for otherwise the balance of air is soon restored by convection, and the slightest mist destroys the effect by a counter-radiation.

§ 186. It was upon these principles that Dr. Wells first explained the formation of *dew* in one of the most beautiful experimental essays which ver graced the annals of inductive philosophy. He ascertained that the formation of this important henomena was always preceded by the cooling f the body upon which it was deposited below the emperature and dew-point of the air by radiation. Hence it is that the best radiating substances, such s the filamentous textures of vegetables, collect his moisture most abundantly, and the short-mown rassplat will be covered with it, while the graveled walk or compact road by its side will remain erfectly dry: and hence it is that dew never forms n a cloudy night, or when there is wind enough to estore the balance of temperature by its circulaion.

§ 187. If in one of the foci of the conjugate mirors before described, a piece of ice, or a glass flask illed with a freezing mixture, be placed instead of a heated body, the thermometer in the other focus will indicate a depression of temperature; and the experiment has sometimes been referred to as proving *cold* to have a positive existence, distinct from heat; but the phenomenon is easily explicable upon the principles which we have already explained, without reference to any new hypothesis. In the new arrangement, the thermometer is the hotter body, and, radiating its heat upon the nearest mirror the rays are projected upon the second, and collected in the focus, where they are absorbed by the ice and as no adequate return is made, the temperature of the thermometer necessarily falls. The effect is exactly the same as that of radiation directed into clear space, just described, which itself was referred by Sir J. Leslie to cold pulses shot downward from the sky.

§ 188. Radiation, however, was ascertained by Sir H. Davy to proceed with greater energy in vacuo than in the air. He, by means of the voltaic battery, ignited charcoal placed in the focus of a small mirror confined in the exhausted receiver of an air pump. The receiver being exhausted to 1-120th, the effect upon a thermometer placed in the focus of another mirror below, was nearly three times as great as when the air was in its natural state of condensation.

§ 189. It has long been known that the heating power of the sun's rays depends upon the colour of the surfaces upon which they fall; and that dark and black bodies are more heated than those which are of light tints or white. The fact was proved by Dr. Hooke and Dr. Franklin, who placed pieces of cloth, of similar texture and size, upon snow, allowing the sun's rays to fall equally upon them. The dark specimens always absorbed more heat than the light ones, and the snow beneath them melted to a greater extent than under the others; and they remarked that the effect was nearly in proportion to the depth of the shade. With regard to this experiment, the different colours stood in the following order: Black, blue, green, purple, red, yellow, white.

It is probable that the absorption of some kinds of terrestrial heat may also be affected, in some degree, by the colour of the objects upon which the rays may fall; but, generally speaking, the absorption and radiation of terrestrial heat are dependant more upon the texture than the colour of the surfaces upon which it impinges or from which it emanates.

§ 190. We have now to inquire how radiant heat is affected by its passage through such bodies as it can penetrate and traverse. All the ordinary phenomena which we observe take place through the medium of the atmosphere, and radiation will proceed through any gaseous medium. The experiment of Sir H. Davy has, however, just been referred to, to prove that it proceeds with least obstruction in vacuo. Observation has also proved that the intensity of the solar rays is greater upon the summit of a lofty mountain than at its base; and it has been calculated that about one fifth of the solar heat is absorbed in passing through a column of 6000 feet of the purest air.

As it is by the passage of light through different transparent media that we distinguish different kinds of luminous rays, so by the same means we are enabled to detect different kinds of calorific rays.

§ 191. In experimenting with colourless and perfectly-polished and transparent glass, one striking difference immediately occurs between solar heat and the radiant heat of terrestrial bodies; it allows the rays of the former, like the rays of light, to pass through it with little obstruction, while it almost wholly arrests the progress of the latter. The rays of heat, as well as of light, are concentrated in the focus of a concave metallic mirror, and the greatest heat which has ever been produced by art has thus been accumulated. The effect is little lessened when the mirror is formed of silvered glass, in which case the rays which are reflected from the bright metallic surface pass through the interposed substance of the glass before they are collected. On the other hand, if the me ror be held before a common fire, a bur will be easily found; but with a glass light of the fire will be reflected, but nc In a similar way, glass lenses refract botl and heat of the sun, and hence are fam tinguished as burning-glasses; but when h any source of terrestrial heat, the most d thermometer will scarcely be affected.

The principal effects which we have described of the reflexion of dark heat conjugate mirrors are immediately arres interposition of the thinnest glass-plate. erty of glass is sometimes usefully emplo it is desirable to see the light of a fire w ing incommoded by the heat; and glass s used to protect the eyes when it is neces spect the action of a hot furnace.

The radiant force, however, is not lo absorption of the glass: it receives a n tion; the glass itself becomes hot, and throw off heat by secondary radiation.

§ 192. This distinction between solar a trial heat is far from being absolute, as v time supposed; for by delicate experime been found that glass will arrest some of t rays, while, on the other hand, it will al of the latter to pass. It has also been a that the quantity of terrestrial heat whic transmitted varies with the nature of it from a good radiating surface of the temp boiling water it is scarcely appreciable, w the flame of a gas-lamp it may be measu air-thermometer. M. de Laroche also ma covery, that the heat which has passed th plate of glass is less subject to absorpt passing through a second.

§ 193. The difference between radian light, and heat in its other condition, is illustrated by the combustion of a flame of hydrogen and oxygen gases, in which no solid matter is concerned. The result is the vapour of water, and the disengagement of the greatest heat which art can command; but it is accompanied by very little light, and if a convex lens be held before it, the radiant heat which will pass through it will scarcely affect the most delicate air-thermometer. If a piece of solid matter capable of resisting its action, such as a wire of platinum, be held in it, radiation will immediately take place. A piece of lime thus presented to the flame undergoes no chymical change, but emits a light which almost rivals that of the sun; and radiant heat is at the same time projected of sufficient intensity to penetrate the lens and to inflame phosphorus at its focus.

§ 194. We are indebted to M. Melloni for almost all that we know, with accuracy, of the passage of radiant heat through different translucent substances. The memoirs in which he has recorded his experiments and deductions have been most justly honoured with the Rumford medal of the Royal Society, and they present a model well worthy of the imitation of those who are engaged in similar physical investigations.

He has ascertained that the power in bodies of transmitting rays of heat is by no means proportioned to their transparency or their power of transmitting rays of light; and among crystallized bodies in particular, he has found that some which are highly transparent intercept nearly the whole of the calorific rays, while others act in a manner directly contrary. These properties are invariably manifested, whatever be the temperature of the source, and become yet more singular at low temperatures; for in the latter case it is found that the ordinary heat of the hand will pass through a solid body of several inches in thickness. Liquid chloride of sulphur, of a deep red-brown colour, will, out of 100 rays, allow 63 to pass; while an equal thickness of colourless spirit of turpentine will only transmit thirty-one; of sulphuric ether, twenty-one; sulphuric acid, seventeen; and of distilled water, only eleven: the case is the same with solid bodies. Different kinds of glass vary in their powers of transmission, from sixty-seven per cent. in flint glass, to forty-nine per cent. in crown glass: while perfectly diaphanous rock-salt will transmit 92 out of every 100 rays; and equally diaphanous alum only twelve. To distinguish those bodies which possess a capacity for calorific transmission, from those which possess a capacity for luminous transmission, he has proposed the term *diathermanous* for the former, as analogous in form to the epithet *diaphanous* applied to the latter. In one experiment he employed a plate of alum, well polished and perfectly transparent, only .06 inches in thickness, and compared it with a plate of smoky quartz 3.38 inches thick, which was of so decided a brown colour that the large letters of a printed page, placed in the fullest light, could not be traced through it; and found that the former allowed only six per cent. of the rays to pass through it, while the latter afforded a passage to nineteen per cent. He also found that the perfectly opaque glass employed in the construction of mirrors, for experiments upon the polarization of light, was diathermanous enough to transmit a considerable quantity of calorific rays: on the other hand, sulphate of copper, which is of a blue colour, and strongly *diaphanous*, is perfectly *athermanous*.

§ 195. The results above detailed were obtained from the burner of an argand lamp; but M. Melloni found that different effects were produced from different calorific sources. The four which he compared together were, the flame of oil, without the interposition of glass; platina wire, kept in a state of incandescence by means of the flame of a spirit lamp (both of which are luminous); a plate of copper, heated to the temperature of 732°; and a vessel of thin copper, blackened on the outside, filled with boiling water (both of which were non-luminous); some of the principal results are shown in the following table:

TABLE XXIII.—*Of Diathermancy.*

Names of the interposed substances—common thickness, 0.102 in.	Naked flame.	Incandescent Platinum.	Copper at 732°.	Copper at 212°.
Rock salt . . .	92	92	92	92
Iceland spar . .	39	28	6	0
Mirror glass . .	39	24	6	0
Rock crystal (colourless)	38	28	6	0
do. (smoky)	37	28	6	0
Citric acid . . .	11	2	0	0
Alum	9	2	0	0
Pure Ice . . .	6	0	0	0

§ 196. Thus it appears that rock salt, successively exposed to radiation from different sources, always transmits immediately the same quantity of heat (and it is the only known substance which thus acts). A plate of any other diathermanous substance will, under the same circumstances, transmit quantities less considerable in proportion as the temperature of the source is less elevated: but the differences between one transmission and another decrease as the plate on which we operate is more attenuated. Whence it follows, that the calorific rays from different sources are intercepted in a greater or less quantity, not at the surface, and in virtue of an absorbent power varying with the temperature of the source, but in the very interior of the plate, and in virtue of an absorbent force similar to that which extinguishes certain species of light in a coloured medium.

ELECTRICITY.

§ 197. An intensity of light, equal to that given by the ignition of platinum in the oxy-hydrogen flame, and attended with great heat, may be produced by the action of the forces which we have called electrical. These are so called from the *electron* or amber in which they were first observed by Thales, 600 years before the Christian era. The more striking phenomena of lambent flames upon the mast-heads of vessels in a storm, or lights upon the spear-points of soldiers, and the flash of lightning, had been also observed with feelings of dread and superstition, but were little supposed, in those early days, to have anything in common with the alternate attraction and repulsion of minute particles of dust by this rare substance after it had been subjected to friction. It was not till 2200 years afterward that the same property of attraction, accompanied under favourable circumstances by flashes of light, was observed to be possessed by glass, sulphur, and sealing-wax, and that the foundations of electrical science were laid by Mr. Gilbert. We are indebted to active observation or experiment for the whole of the superstructure, mere passive observation or common experience having had but little influence upon its progress. Electricity is as widely diffused as energetic in its character, and at least as important in the economy of the material universe as heat itself; but its properties are more recondite, and necessity has not given to the human race that early command over this power, upon which its very existence has depended in the latter case. Such a command will probably result from the higher exercise of the intellectual faculties of man, and may be destined to requite his patient industry with the acquirement of power, of which only inadequate anticipations can as yet, perhaps, be formed.

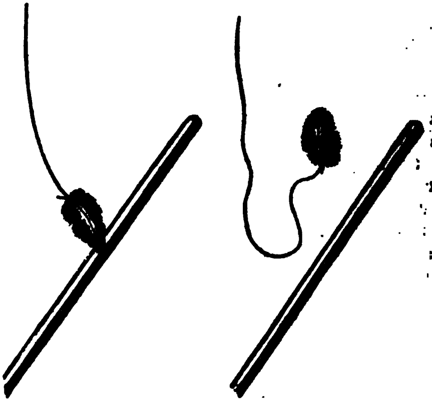
§ 198. It will be remembered that we traced the origin of heat to five principal sources; and from four of the same sources we also derive the new force which we are about to examine; while analogy, as well as the uncertain results of vague experiments, lead us to believe that the fifth, or the solar rays, will hereafter be found capable of imparting this subtle influence. It is freely evolved by the mechanical action of heterogeneous substances; still more abundantly by chymical action; it is a product of animal organization; and as electricity, under certain conditions, is capable of evolving heat, so heat, on the other hand, is capable of exciting electricity. Like heat, it adds nothing to, and subtracts nothing from, the weight of bodies in which it is excited; but, unlike heat, it is not opposed to cohesion, and does not increase the volume of homogeneous masses, or loose the chain which binds their particles together. It is capable of acting upon masses of matter in opposition to gravity, and it is also capable of the most energetic influence upon its constituent atoms. Every form of matter may be excited in its action, and it may be transferred from one portion of matter, in which it has been called forth, to another previously in a neutral state.

§ 199. The apparatus we shall first describe is of extreme simplicity, but the instruction which we derive from it is of the greatest importance.

We have already seen (§ 14) that if we suspend some light substance, such as a feather or a pith-ball, by a silken thread, and then approach it with a dry glass tube which has been rubbed with silk, the suspended substance will be attracted to the glass tube from a distance, and adhere to it for a moment, but will afterward recede from it; and, after its separation, so far from the glass exerting any attraction upon it, it will strongly repel it from its surface. If we substitute a stick of sealing-wax for the glass tube, and rub it with a dry, warm flannel, we may produce the same phenomena of attraction and repulsion upon a fresh feather, and in the same order. But now, if we present the excited wax to the feather which has received the repulsive property from the glass, or the excited gl to the light substance which is in a state to be pelled by the wax, strong attraction will be ma fested in both cases.

Moreover, we find from experiment that not o does the originally excited glass or wax attract repel those light portions of matter, but they co municate, by contact, the same properties to the so that two feathers, after having been attract will not only be repelled by the wax or glass spectively, but will repel each other, and their co ponent fibres will become self-repulsive: but feathers which have received the property fr the different substances, though relf-repulsive, strongly attract each other. This transfer of po er, it must be observed, is very different from process of original excitement.(35)

(35) The annexed figure will convey an idea of the fe when in its natural state attracted by the excited glass,



when in an electrified state repelled from the similarly ele fied rod.

300. Simple as are these phenomena, they com-
the first principles of electrical science. From
we learn that the friction of glass and resin
municates to these substances a state of activi-
ith regard to other bodies, which is similar in
wo cases, but opposite in its nature: that this
of activity once excited in them by friction,
are capable of communicating to other bodies
imple contact, and that it is manifested in all
s by the mutual repulsion of similarly active
es, and the mutual attraction of oppositely ac-
bodies.

ow these two states of activity it is obviously
ssary to distinguish by some appropriate desig-
n, and they might properly be termed the *vit-*
and *resinous*, from the two substances which
first observed to possess the power of com-
icating them. But in a subject so remote from
llustrations of common experience as is that
lectricity, it has been found necessary to do
e than this: to adopt some hypothesis, with re-
to the subtle influence thus called into action,
h may serve as a clew to guide the student
ng the multiplicity of its phenomena. When
s informed that there are two such theories,
which the facts may be explained with equal
ability, he will need no other caution to distin-
n between the importance of the facts and in-
ions, and the thread which is employed to
g them together.

301. It was imagined by M. du Fay that the op-
e electrical forces were peculiar to certain kinds
atter; that they were referable to two highly
ic, imponderable fluids, the particles of which
self-repulsive, but attractive of each other; and
one, which he called the vitreous electricity, was
ys elicited from glass, and the other, which he
ed resinous electricity, from resinous bodies. In
orm in which the hypothesis of two fluids, which

goes by his name, is now adopted, it is greatly indebted to the observations and modifications of Mr. Symmer, who showed that when two bodies are rubbed together, both become excited; and that one of them always possesses the vitreous, and the other the resinous virtue. The two fluids exist in all unexcited bodies, in a state of combination and neutralization, when no electrical phenomena are apparent. Friction occasions the separation of the two fluids, and the electrical action continues till an equal quantity of that kind of electricity which has thus been withdrawn from the other, has been restored and reunited with it.

§ 202. Dr. Franklin proposed a different and no less ingenious explanation of electrical phenomena, in some respects more simple than the preceding; dependant also upon the properties of an imaginary highly elastic fluid, which, upon his supposition, was single, and pervaded all matter. This fluid is self-repulsive, but attracts the ultimate particles of matter, which the hypothesis farther requires should be considered as self-repulsive when deprived of their natural portions of the electrical fluid. The opposite states of electrical excitement, according to this view, depend upon the increase or diminution of this elastic fluid. When a glass tube is rubbed with a silk handkerchief, the electrical equilibrium of the fluid in the two substances is disturbed; the glass acquires more than its natural quantity, and is overcharged: the silk retains less than its natural quantity, and is undercharged. Thus, electrical repulsion takes place between two bodies, both of which contain more or less than their natural quantity of fluid, and electrical attraction is only excited between two bodies, one of which contains more or less than the other.

According to the theory of Du Fay, the two states denominated *vitreous* and *resinous*; according to theory of Franklin, they are distinguished as *tive* and *negative*.

§ 2[illegible] It is quite obvious that both these hypotheses cannot be true; and it is highly probable (indeed, some of those best qualified to judge would say that it is certain) that neither of them presents us with the real process or mechanism of the phenomena. The progress of science begins clearly to indicate that the whole class of electrical facts will one day be included in some higher generalization than either of those by which they are at present grouped together; and, indeed, an attempt has been made (and according to mathematicians, who are best qualified to judge of such high exercises of reason, not without success) to connect, in one general theory, all attractive and repulsive forces, not excepting the universal force of gravity itself.*

Such views, however, must not be presented to beginners in science, and probably it will not be in the present age that the teacher will be able to dispense with one or other of the scaffoldings, by the assistance of which the fabric of electrical science has been built up to its present dimensions and proportions. The hypothesis of two fluids has had the advantage of having been submitted to mathematical investigation by M. Coulomb and M. Poisson; but even in the mathematical investigations it is easy to substitute one theory for the other, by a very simple transformation of the formulæ.

In making the legitimate use of either theory to assist him in attaining *clear ideas* of the connexion of the phenomena, the student should never forget that such hypothetical fluids may have no real existence, and that the peculiar actions which he is called upon to contemplate may be referable to powers with which matter may have been endowed, without the intervention of any such medium as has been imagined. Indeed, the late rapid advance of the science seems rather to countenance th[illegible]ore simple view of the subject; and one of the g[illegible]test difficulties with which the teacher has to contend at present, is a certain confusion of view and of language which almost necessarily attends this transition state. After this explanation, however, it is to be hoped that no difficulty will be felt at the indifferent employment of the terms *vitreous* and *resinous*, or *positive* and *negative*, to denote those peculiar states of matter by which the phenomena which have been just described are produced.

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* MOSOTTI.—Sur les Forces qui régissent la Constitution intérieure des Corps.

It is a necessary consequence of either of the hypotheses which we have just stated, that one species of electricity can never be excited without a simultaneous production of the other; and, in fact, the opposite electrical states are always such as exactly to neutralize each other in the rubber and the body rubbed. This conclusion is quite borne out by the results of experiment. Even with the glass tube and silk, we shall find that it is not only the glass, but the silk also, which, after friction, attracts the feather; and after the feather has been repelled by one, it will be strongly attracted by the other. We shall presently find more perfect means of demonstrating the exact equality of the opposite forces.

§ 204. After either electrical state has been conferred upon a body, for instance, on the glass by friction, or on the feather by contact, it will very slowly return to its natural state in a dry atmosphere, unless it be touched with some other substance; but the nature of the substance brought into contact with it is by no means indifferent to the result. The naked hand will speedily remove the electricity, or any metallic body still more readily; but dry glass, resins, silk, sulphur, will not prove effective. From this difference in their power of conveying or conducting away the electricity, bodies have been divided into two great classes of *conductors* and *non-conductors*. In the former, the elastic fluids are supposed to travel with little or no impediment, and with a velocity infinitely exceeding that of the similar propagation of heat, and only comparable with light itself; while in the latter their passage is obstructed; they seem to adhere to their substance, and to be incapable of transmission from particle to particle.

Although we may thus classify all substances into conductors and non-conductors of electricity, we shall, however, find the two classes passing by insensible gradations one into the other. There is, in fact, a progressive order in which all bodies may be arranged, beginning with that substance which possesses either property in the most perfect degree, and proceeding through the gradations of other substances to the opposite extremity of the scale. In the following table, the left hand column commences with the most perfect conductors, and ends with the least perfect conductors; the right hand column commences with the least perfect conductors, and ends with the most perfect:

TABLE XXIV.—*Electrical Conduction.*

CONDUCTORS.	Spermaceti,
Metals.	Glass.
Charcoal, plumbago, &c.	Sulphur.
Fused chlorides.	Fixed oils.
" iodides.	Spirits of turpentine.
" salts.	Resins.
Strong acids.	Ice.
Alkaline solutions.	Diamond.
Water.	Shell-lac.
Alcohol.	Oxalate of lime.
Damp air.	Dry gases.
Vegetable and animal bodies.	INSULATORS.

This distinction of bodies according to their conducting power, regards them as *masses;* it is probable that the constituent particles, whether of conducting or non-conducting matter, are individually conductors, and capable, as such, of receiving a charge of electricity. In this distinction we a presented with a close analogy in the conducti of heat; for the particles of aeriform matter rea ily become heated, although heat travels amon them by conduction with the greatest difficulty.

§ 205. The instantaneous way in which electrici passes along a good conductor, and the advantag which may be taken of the non-conducting powe of bodies to prevent its escape from substances i which it may be required to confine it, may both shown by a very simple experiment. Suspend metallic wire of many yards in length, by string white silk, from any convenient supports, and han to one of its extremities two strips of gold leaf, s that they may be parallel to each other, and nea in contact: present any excited body to the oth extremity, and the slips of gold-leaf will instantl repel one another, and diverge; proving, whatev the length of the wire may be, that the influence i confined within its limits, and instantly pervades from end to end. If the wire be now divided, an a connexion be made between its two ends by th smallest possible loop of silk, the electric fluid wi be found incapable of passing through the interv of non-conducting substance. We thus make u of this difference in the conducting power of bodi for the purpose of *insulation*. By supporting goo conducting substances upon non-conductors, we ca cause them to retain any electric charge which w may communicate to them; they thus become th off or insulated from any ready channel by whic the fluid might pass away, or attain to that state equilibrium which it is always striving to effec Without this power the electric forces could scarc ly have been made the subjects of experimental i vestigation.

When a non-conducting substance becomes cha ged, either by friction or otherwise, with electricit it will only partially give up the fluid on its surfac to a non-insulated conductor at the point of contact; but a charged insulated conductor will instantly part with the whole of its charge. In the former case the fluid is incapable of moving from point to point, while in the latter it will traverse any space in any direction without apparent obstruction.

If, again, a small charged conductor, such as a brass ball, be brought in contact with a smooth plate of resin, a portion of the electric fluid will adhere to the resin at the point where the two bodies touched, but will spread itself only to a very minute distance round.

§ 206. It was formerly supposed that the two great classes of conductors and non-conductors might be designated as *non-electrics* and *electrics*: the former name denoting a capacity of electric excitement, and the latter a total incapacity; but this distinction is quite inaccurate. If we hold a rod or tube of metal in our hand, and rub it with a silk handkerchief, it is quite true that it will exhibit no signs of excitation. The reason is, that both our bodies and the metal being good conductors, the electrical fluid passes away as it is disengaged; but if we insulate the metal—cut it off, that is, from communication with the hand by means of a glass handle—we shall find that upon friction it will become electrical, like the glass or the resin. The friction of two metals together, provided both be insulated, will excite electricity; and if we sift zinc filings through a copper sieve provided with a glass handle, we shall find that the sieve and the filings will be oppositely excited.

§ 207. The mode of ascertaining the existence and nature of any electrical excitement is very simple. For this purpose we have recourse to a beautiful little instrument, called the gold-leaf electrometer. It consists of two slips of gold-leaf, suspended from a brass wire terminating in a small plate, within a cylinder of glass. The wire is insulated by the glass, and more effectually by passing it through a glass tube covered with a varnish of shell-lac and packed with silk. The leaves are made to diverge by contact with some body in a known state of excitement, as with a stick of sealing-wax rubbed with woollen; if the approach of the body, whose state we wish to determine, cause the leaves to diverge still more, we conclude that it is resinously electrical; if, on the contrary, they collapse upon its approach, it is a proof that it is in the vitreous state.(36)

There is another mode, which is still preferable to this, as affording not only an indication of the kind of force which is required to be tested, but also an accurate measure of its intensity. It consists of a needle of shell-lac suspended from a fine thread of spun glass. At one extremity of the needle is placed a small disc of paper or other conducting substance, which, being thus insulated, is capable of receiving and retaining a charge. When another electrified body is brought near to this, the kind of electricity which has been communicated

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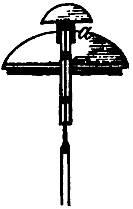
(36) Bennet's gold-leaf electrometer is here represented, the leaves being in a state of divergence from a charge which has been communicated to them.

The improved mode of insulation introduced by Mr. Singer is shown in the section *a*. The wire to which the gold leaves are attached passes through a glass tube packed with dry silk, and is covered by a brass cap screwed to its upper end, by which it is protected from dust and damp.

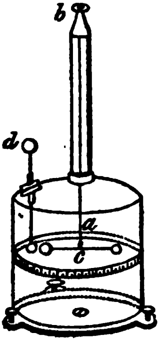


to it being known, it will indicate by its attraction or repulsion the species of electricity thus brought within its sphere of action; and the intensity of the force may be measured upon a scale by the amount of torsion in the thread which may be required to bring the two repelling bodies into mutual contact.(37)

§ 208. Experiment has demonstrated that the same substance is not always similarly electrified by friction; but that its electrical state is determined partly by the condition of its own surface and partly by the body with which it is rubbed. Thus flint-glass with a smooth surface, when rubbed with woollen cloth, becomes vitreously electric; but if its surface be roughened, and it be rubbed with the same cloth, it will be resinously electrical.

Smooth glass, rubbed with every substance which has been tried, except the fur of an animal, as a catskin, becomes vitreous: with a catskin, resinous.

White silk rubbed with black silk, metals, or black cloth, is vitreous; rubbed with paper or the hand, resinous.



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(37) This cut represents Coulomb's torsion-electrometer, or electrical balance. *a b* is a thread of silk or spun glass, from which the needle of shell-lac, *c*, is suspended. It is attached to the screw, *b*, by which it can be twisted round its axis. The needle carries a gilt ball of pith or a disc of paper at one extremity, which is balanced by a counterpoise at the other; *d* is a metallic wire passing through the glass shade, and terminated by a metallic ball at each end. The ball of the needle and the interior brass ball of the wire are brought into contact by turning the screw, *b*, and the index then points to 0 on the scale, which is marked upon the circumference of the glass.

Sealing-wax, rubbed with the metals, is vitreous with cloth, paper, or the hand, resinous.

§ 209. It was first observed by Otto de Guericke and Hawksbee, that the friction of glass and resinous substances not only produced the phenomena which we have just described, but, under favourable circumstances, was accompanied by a rustling or crackling noise; and, when the experiment was made in a dark room, by flashes and sparks of light upon their surfaces. When once the attention has been directed to the observation, most persons will find that such phenomena of electrical light are familiar occurrences, and often present themselves in suddenly drawing off from the person a silk stocking or a flannel waistcoat, or in the friction of long hair by combing. How small a degree of friction is sufficient to excite electricity in the human body, is shown in a striking way by placing a person upon an insulating stool with glass legs. If in such a position he place his finger upon a gold-leaf electrometer, and another person flip him lightly with a silk handkerchief, the leaves will immediately repel each other.

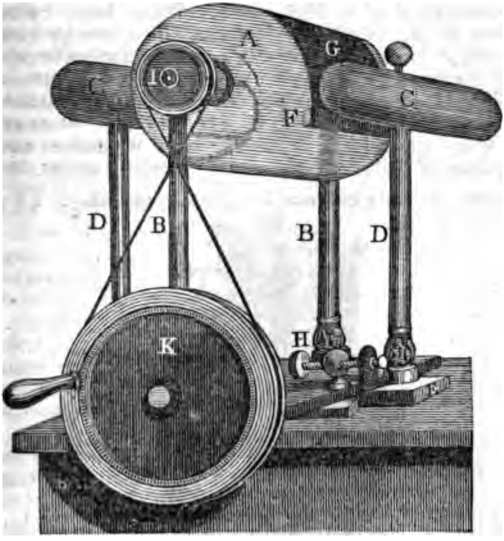
§ 210. We may now proceed to describe the means of producing these effects upon a large scale, and the different modes which have been devised of exciting, collecting, and measuring the electric fluids.

The electrical machine, as it is called, whatever form it may assume, resolves itself into a more or less perfect way of applying to glass the friction of silk or some other dissimilar substance, as in our fundamental experiment, and of drawing off the electricity as it is excited, and collecting it in a good insulated conductor. In machines of the more perfect construction, not only is the vitreous electricity collected in what is called the prime conductor but the resinous also is accumulated by in-

ulating the rubber and connecting it with a metal-
ic cylinder.(38)

Experience has shown that the most effective ex-

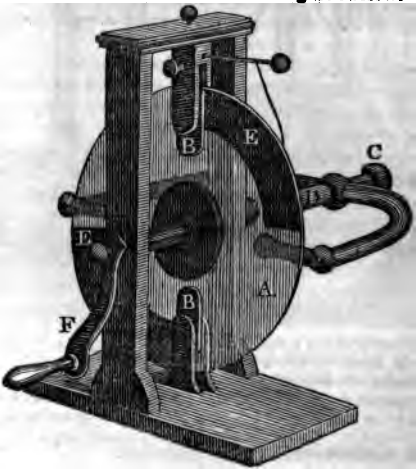
(38) The following figure represents the cylinder electrical achine; A is a glass cylinder, properly mounted, to turn upon wo stout glass pillars, B B, strongly fixed upon a wooden frame. t is made to revolve rapidly, by means of the multiplying heels I and K. C C are two brass cylinders, supported upon wo glass pillars, D D, in a position parallel to the glass cylinder;



to one of these a cushion, F, with a silk flap, G, is attached which is made to press against the glass by a spring, its dis ance being capable of adjustment by means of the screw H. The opposite brass cylinder has a row of points attached to it, o which the silk flap, G, extends. The latter goes by the name f the prime conductor or the positive conductor; the former s distinguished as the negative conductor.

citer of glass is a metallic substance; and whe
soft amalgam of mercury, tin, and zinc is spr
upon the rubber, it forms a flexible metallic surf
which is perfectly adapted to the purpose and gre
ly heightens the effect. The best proportions
the metals have been found to be one part of tin
two of zinc, fused together, and mixed while
with six parts of mercury The mixture must t
be triturated in a mortar, with a little lard, to
consistence of a thick paste. When large cy
ders or plates of glass are made to rotate by c
venient mechanical means, pressing against cu
ions covered with this metallic coating, they are
pable of producing all the phenomena of attract
and repulsion in a high degree, and their state
intense excitement is accompanied by flashes
sparks of brilliant light, and a crackling sound.(

(39) The Plate Electrical Machine is figured below. A



When the prime conductor is placed in its proper position it receives from the glass, without contact with it, a charge in the form of a stream of fire, which, whatever may be the size of its surface, rises to nearly the same intensity as that of the original source; and which, being thus accumulated in quantity, will wholly pass off at once to any uninsulated conductor, or will instantaneously divide itself with an insulated one, by means of a dense spark. Similar phenomena may be obtained with the conductor attached to the rubber; but to obtain the highest effect from either, it is necessary to make a good conducting communication from the other to the ground. The reason of this is, that when the two electricities are in presence of each other, they counteract and limit each other's intensity: by connecting either conductor with the earth, its charge is spread over an indefinitely large surface, and virtually annihilated. That the two conductors are in opposite electrical states, is easily proved by suspending from each some light substances, which will strongly attract each other when charged: and that the two charges are exactly equal, is shown by making a good metallic communication between the two, when all signs of excitement will cease in both.

§ 211. And now, it may be asked, Where does the charge reside in a good insulated conductor? Does it diffuse itself, like heat, throughout the whole of its substance, or is it confined merely to its surface? That it is merely superficial is susceptible

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circular glass plate, mounted upon a brass axis, and turning in a stout wooden frame by means of the handle F; as it revolves it passes between two pairs of cushions B B, which are pressed lightly against it by means of screws; C is the brass prime conductor, supported upon the stout glass arm D; it is armed at its two extremities, which are opposed to the plate, with two rows of points, which meet the ends of the two silk flaps E E, which are attached to the cushions B B.

of proof in several ways. If we take a solid globe of metal, and electrify it to a certain amount, and then bring it in contact for a moment with a globe of similar dimensions, made of the thinnest shell of the same metal, we shall find that the charge will distribute itself equally between the two. If we take a hollow sphere, with an aperture at its upper part, and, having given it a charge of electricity, touch its interior with a small insulated ball, upon bringing this proof-ball in contact with an electroscope, we shall find that it will afford no signs of having received a charge; but, on the contrary, if we touch the exterior of the sphere, it will carry away a part of the charge with it, and affect the instrument.

How much the intensity of the electric charge depends upon the surface, may also be very elegantly shown by means of a metallic riband, coiled up by a spring upon the top of a gold-leaf electrometer. When this apparatus is electrified, the leaves, of course, repel one another in proportion to the charge which they receive. If the riband be now drawn out by a silk thread or other insulating handle, the leaves will approach each other in proportion to the enlargement of the surface over which the electricity becomes diffused; and, as it again coils itself up, they will expand to their original amount. Here it is seen that, the quantity of the charge remaining the same, its intensity decreases with the increase of the surface over which it is suffered to diffuse itself, and that the quantity of electricity which a given portion of matter may receive depends upon the dimensions of its external surface.

§ 212. The next question which presents itself is, How does the electricity arrange itself around surfaces of different forms? in a layer of equal intensity in every part, or otherwise? This question is readily submitted to experiment by means of a small insulated disc, which, being applied to any part of the surface of an electrified conductor, becomes virtually a part of that conductor; and, upon being removed, carries with it a portion of the charge, having the same intensity as that of the point to which it was applied, and which may be measured by the torsion electrometer.

In this way it has been proved that, in the case of an electrified sphere, the intensity is the same at every part of the surface; but this is the only form of surface upon which this equal distribution takes place. If two similar spheres be placed in contact with one another, it will be found that there are two points of greatest and equal intensity on their opposite sides, in a line with their points of contact where the force will be null. So in a cylinder or bar of metal, the electrical intensity will be much greater at the two ends than in the middle, and this inequality of distribution will increase very rapidly in proportion to the diminution of the diameter of a cylinder of given length.

If two balls of equal diameters be placed together, the maximum intensity of the extreme point of the smaller sphere will be higher than that of the corresponding point of the larger; and by adding a series of balls in contact with each other, all gradually decreasing in size, the intensity will increase upon the smaller as the diameter decreases. We can conceive a succession of such balls gradually diminishing till the series ends in a mere point, at which the electric tension will be at its maximum. In consequence of this law of distribution, a powerful dispersion of electricity takes place from all bodies of a pointed form; the intensity upon them increasing to such an extent that the surrounding insulating medium of air gives way before it, and no longer suffices to constrain it.

§ 213. Our attention has hitherto been directed to the electricity which is developed upon the surfaces of two dissimilar substances by mutual friction, or which has been transferred to other bodies from such excited substances by contact and direct communication. We have now to examine a remarkable influence which an electrified body exerts upon other bodies at such distances from it as prevent the direct transfer of any portion of the charge. The neutral state of an insulated conductor in its immediate vicinity will be destroyed. If it be in the form of a cylinder, furnished with electroscopes at each extremity and also at its centre, when one end is placed near the charged substance we shall find the two extreme electroscopes indicating electrical activity, while the centre remains quiescent. Upon slowly withdrawing the excited body, these secondary electrical signs gradually decrease, and finally disappear upon its complete removal or discharge. Upon examining, by the proof-plane and torsion electrometer, the kind of electricity developed by this distant influence, we shall find that the end of the cylinder which is the nearest to the originally charged body is in an opposite state to that body, and the farthest end in the same state; that the cylinder has, in fact, had a *polar state* communicated to it (§ 15). This distant action of an electrified body, by which its own charge is in no degree lessened, is distinguished by the name of *induction:* the secondary state of the neighbouring body is called *induced electricity:* and the body itself is said to be under induction. Farther, the originally active body is conveniently distinguished as the *inductive* body, and that under its influence as the *inducteous* body.(40)

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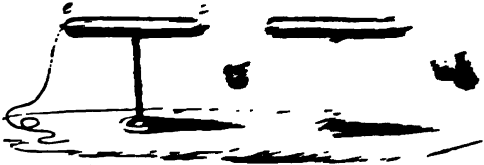
(40) Let *a* represent an electrified ball, and *b c* an insulated metallic cylinder near it, the feather attached to the end, *b*, will be attracted, and show that it is in an opposite state to that of the charged ball. If *d e* be an insulated cylinder, placed near the first, it will also show signs of electrical change, and the extremity, *d*, will be in an opposite state to the end, *c*, of the

[illegible]

[illegible] that [illegible] the [illegible] by a [illegible] [illegible] if [illegible] ted from [illegible] [illegible] both [illegible] of [illegible] of [illegible] [illegible] former [illegible] state.

This [illegible] of [illegible] however [illegible] distance [illegible] Through [illegible] of one [illegible]

first [illegible] each [illegible]



first cylinder [illegible] the two cy[illegible] other, and the intensity of all will rise by connecting the last with the ground.

The arrangement which strips of conducting substances, tied together and electrified at one end, assume, indicate the direction of the lines of induction and the influence of surrounding objects. Strips of paper, placed upon a long rod in connexion with the prime-conductor of the machine, in the centre of a large apartment, will open out equally like radii from the centre of a sphere; but if any conducting body be approximated to them in their charged state, they will incline towards it from the concentration of the force upon its nearer surface.(41)

Even the prime conductor of the electrical machine itself may be of such a construction as to afford proofs of no electrical charge upon some portions of its surface, while strong sparks may be drawn from others. If we place eight or ten metallic rods upon it, each terminated with a ball, and all diverging from one common centre, strong sparks may be drawn from each extremity, while the surfaces of any of the interior rods of the group may be tested with the proof-plane, and will give no indications of charge.

§ 215. Induction requires no sensible thickness in the conductors which may be used to limit its extent; an uninsulated leaf of gold may be made very highly vitreous on one side, and as

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(41) This is illustrated by the ridiculous figure of the *head of hair*, which is a common electrical experiment. When electrified, the hair stands on end; and each fibre, as if in a state of repulsion from its neighbour, is attracted by, and radiates towards, the point which is nearest to it in the oppositely induced state.

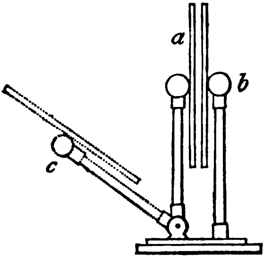
highly resinous on the other, without the least interference of the two states while the inductions continue. But with regard to the insulating media, their thickness has an immediate and important influence on the degree of induction. There is, perhaps, no distance so great that induction cannot take place through it; but, with the same original charge or constraining force, it takes place the more readily according as the extent of the medium through which it is exerted is lessened. The particles of the latter, though thrown into a forced condition during the action, tend to return to a normal state; and the fewer there are exerting this tendency, the higher will be the condition they acquire, and the larger the amount of inductive action exerted through them.

§ 216. If an insulated brass plate be connected with a gold-leaf electrometer, a charge of [illegible] may be communicated to it [illegible] in consequence of induction through the air to the [illegible] distant surrounding objects [illegible] indicated by the divergence of the leaves. [illegible] in this state, if another [illegible] plate [illegible] be opposed to it, as it is made to approach [illegible] the leaves of the electrometer will fall [illegible] the process of induction being directed almost wholly through the thin intervening stratum of air to the second plate, which will itself be in the [illegible] state. If the second plate be now uninsulated, by connecting it with the ground, the leaves will still remain collapsed, as the electricity of the same kind with that of the inductive body will be rapidly dissipated by diffusion over the indefinitely large surface of the earth. When the second plate is again withdrawn, the leaves will reopen to their former extent, indicating that the inductive process has resumed its former direction.

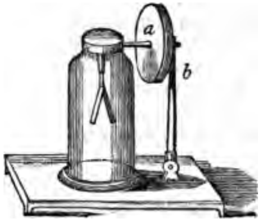
§ 217. The inductive plate, when under the influence of the second plate, is capable of receiving a higher charge of electricity, and the leaves of the electrometer may be made to open out to the same amount as in the absence of the latter; for the charge will not only be sustained by the inducteous plate, but also by surrounding objects as before it was placed in its position. When, under these circumstances, the second plate is again removed, the accumulation which has been effected will be indicated by an expansion of the leaves far beyond their original amount, the whole being now thrown upon the surrounding conductors.

This is the principle of the action of an instrument which has been called the *condenser*, by which small quantities of electricity may be accumulated and rendered apparent.(42)

§ 218. The attraction of bodies free to move, by others in an electrified state, is in all cases owing



(42) One form of the condenser is exhibited in this figure, in section: *b* is a brass plate supported upon a glass stem; *a* is another brass plate of the same size as the former, capable of being placed as close to it as possible without touching. It is supported by a brass stem, which moves upon a hinge-joint; it is shown in a second position at *c*.



A condenser, similar to that in the preceding figure, is here shown, in connexion with a gold-leaf electrometer.

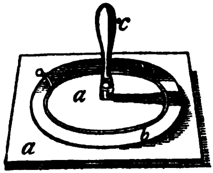
to the previous development of the opposite condition by induction. This is beautifully shown in an arrangement of Mr. S. Harris, in which a circular plate of gilded wood is suspended by insulating threads from one of the arms of a delicate balance and counterpoised. Upon its upper surface is fixed, by a hinge-joint, a small lever of straw terminating in a pith-ball. When a similar plate charged is brought under this suspended plate, the pith-ball indicates by its repulsion the induced state which precedes the descent of the plate from the attractive force. When they come in contact, the original charge is divided between the two plates, and mutual repulsion appears to take place. This apparent repulsion again is dependant upon the attraction of each in opposite directions, by the inductive action which it exerts upon surrounding bodies.

A pith-ball, or other light substance, placed upon a conducting surface under an electrified plate, is electrified by induction, and drawn upward; but when it comes in contact with the plate, its induced state is destroyed, it is charged with similar electricity, is attracted downward, and parts with its charge.

In a similar way induction always precedes the charge in insulated conductors, and the prime conductor of the machine has the resinous state strongly elicited upon its point previously to its becoming charged with the vitreous electricity of the excited glass.

§ 219. There is another instrument of electrical research, called the *electrophorus*, which is well calculated to illustrate several interesting points of the process of induction. It consists of a plate of resinous matter, about half an inch thick, placed upon a piece of metal. A second polished metal plate, of rather smaller diameter, is fitted with a glass insulating handle, by which it can be lifted on or off the upper surface of the plate of resin. When the resin has been excited by gentle friction with dry fur or flannel, and the plate placed upon it by its handle and immediately removed, it will be found to have received a very feeble charge of resinous electricity by contact. If it be then replaced and uninsulated by contact with the finger or a metallic rod, and again lifted by its insulating handle, it will be found to give a strong spark of vitreous electricity. This process may be repeated an unlimited number of times without requiring any fresh excitation of the plate, which circumstance, as well as the opposite nature of the charge, shows that the electricity of the moveable plate is not derived in the way of charge from the resin, but is the result of the process of induction. The metallic plate cannot, in fact, be considered in absolute contact with the resinous, owing to the inequalities of the surface of the latter: the former, therefore, is precisely in the state of a conductor opposed to, but not touching, an electrified surface; and, therefore, capable of being rendered electrical by induction when uninsulated by contact of the finger. As the resin loses but little of its acquired charge by each contact, the instrument is capable of being used as a permanent source of electricity always at command, and in a dry atmosphere will remain in action for many successive months.(43)

§ 220. When the electrophorus is placed upon an insulating stand, its lower plate is always found in an opposite state to the upper one; proving that the friction of the upper surface communicates a polar state to all the particles of the resin which penetrates even through its mass.



(43) This figure represents the electrophorus. *a a* are two metallic plates, and *b* a plate of resinous matter. The upper metallic plate has an insulating handle, *c*, by which it can be lifted ftom its position, and replaced.

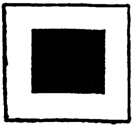
This charge it is necessary to remove by contact with an insulated substance, to give full effect to the opposite charge upon the upper plate.

§ 221. The phenomena of induction, which we have been examining, we have considered principally as produced by the intervention of the aerial molecules of our atmosphere: we must now enter upon a closer investigation of the inductive properties of other insulating media. Liquid oil of turpentine is capable of undergoing the same polarization of particles as an insulated conductor; and we have had reason to conclude from one of the properties of the electrophorus, that resinous solids are susceptible of the same forced arrangement under the influence of an excited charge. All insulating substances, or substances which are capable of this peculiar development of the two opposite electrical forces, whether solid, liquid, or aeriform, Dr. Faraday classes together under the name of *dielectrics*.

§ 222. We have seen (§ 216) that, by approximating a metallic plate to a charged conductor, so as to leave an intervening portion of air, the conductor is capable of receiving a higher charge, and the air of assuming a higher polar tension, than when the charge is sustained by distant objects in ordinary circumstances. The tension increases with the thinness of the aerial stratum, and is in inverse proportion to the squares of the distances of the two plates. It is necessary to the attainment of the maximum effect, that the second plate be insulated; that is to say, that it be prevented itself from assuming the polar state by the annihilation of its remoter associate force, by the reaction of which the induction would otherwise be limited: or, more accurately speaking, by allowing it to diffuse itself over the indefinitely large surface of the earth, thereby proportionately lowering its tension. The rise of the force, under these circumstances, is ultimately limited by the mobility of the particles of the air, in consequence of which the equilibrium is restored either silently or in the form of a spark.

But if a solid dielectric be substituted for the air, the state of tension is capable of rising to a degree limited only by its cohesive force. Thus, if a plate of glass be coated on both sides with tin foil, within an inch or two of its edge all round, and one side be placed in connexion with the prime conductor of the electrical machine, we shall have an exactly similar arrangement to that of the two plates of the condenser, with its interposed stratum of air. Upon connecting the opposite coating with the ground to destroy its polar state, the particles of the glass are forced into a polarized or constrained condition by the electricity of the charging apparatus; which is sustained till the return of these particles to their natural state from their state of tension, whenever the two electric forces are allowed to neutralize themselves by some other channel, as by the interposition of a good conducting body between the coatings. The quantity of force which may be thus accumulated may in some degree be estimated by the number of turns which it may be necessary to give the machine before the intensity, as measured by the electrometer, rises to the same degree as that which is almost instantaneously communicated to the conductor, when the charge is sustained alone by the inductive medium of the air to surrounding objects, and will be found to be in proportion to the coated surface of the glass.(44)

§ 223. There is no difficulty in perceiving that the opposite surfaces of the dielectric and conductors may be arranged in different forms without impairing the effects; and experience has proved that coated jars or bottles are the most convenient for extensive



(44) A plate of glass is here represented, with a coating of tin foil, to which a similar one on the opposite side corresponds.

apparatus of this condensing kind. The honour of the discovery of the means of accumulating electricity is generally given to a Dutch philosopher of the name of Muschenbroek, who resided at Leyden, and hence the name of the Leyden jar, by which the arrangement is commonly known. He instituted some experiments for the purpose of ascertaining whether a charge might not be given to electrified bodies, by surrounding them with more perfect non-conductors than the air; and with this view he attempted to charge some water contained in a glass vessel. An iron nail passed through a cork, and communicated with the water in a vial, which was grasped in the hand. After holding the nail for some time in contact with the prime conductor of the machine, he attempted to remove it with the other hand, and experienced a violent concussion in the arms and across the breast. This experiment soon became popular, and the sensation it produced was called the electric shock. The first experimenters gave ludicrous and exaggerated accounts of its effects, which served to excite curiosity to a very high degree; and in the very year of its discovery it was shown by itinerant exhibiters in every part of Europe. The principles upon which this accumulation or power depended, were not, of course, understood; but it is now obvious that the water in the vial, and the hand which grasped it, acted, although more imperfectly, as the two coatings of the glass. When the nail was touched with the other hand, a good conducting communication with the two surfaces was opened, by means of the fluids of the body through which the tension and polarity of the forces were destroyed.(45)

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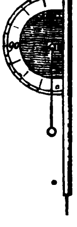
(45) This is the usual form of the Leyden jar The interior coating reaches up to nearly the same height as the exterior, and is in metallic

The *quantity* of electricity which may be accumulated in a Leyden jar depends upon the extent of its coated surface; its *intensity*, upon the thinness of the glass.

§ 224. When large quantities of electricity are required for experiment, it is found more convenient, in general, to employ several jars instead of one; and a number of jars arranged together, with their internal and external coatings respectively in metallic communication, is called an *electrical battery.*

In practice it is found impossible to diminish the thickness of the glass beyond a certain extent; for the constrained position of its polarized particles becomes at length so extreme, that the cohesive force itself gives way, and the charge passes with violence through a hole which it pierces for itself in the weakest part of the plate.

§ 225. A method has already been indicated (§ 222) of roughly estimating the quantity of electricity in a charge, by the number of turns of the electrical machine. Its intensity may be approximatively determined by the amount of repulsion between any two moveable bodies under its influence; or, rather, by the amount of their opposite attractions by surrounding bodies under their inductive influence. An instrument was contrived by Henley for measuring this effect upon the graduated arc of a circle.(46)



§ 226. But we are indebted to Mr. Snow Harris for an accurate instrument for as-

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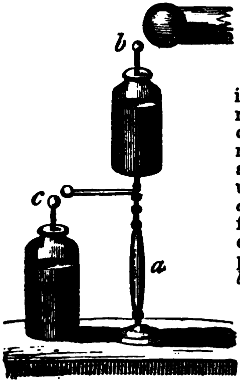
communication with the brass ball by means of a wire passing down to the bottom.

(46) The Quadrant Electrometer is here represented. It is screwed upon the jar or battery whose charge it is intended to indicate; and as it increases, the light index, composed of a straw and terminated by a pith-ball, moves from its centre of suspension, and measures the intensity upon the graduated semicircle.

certaining this important point, founded upon the following principles.

From what has preceded, it will be obvious that, if a Leyden jar be insulated, it will be incapable of receiving a charge of any considerable amount. In proportion as the vitreous electricity is communicated to its interior coating, it is necessary that the same quantity should be removed from the exterior, which would otherwise counteract the resinous electricity by which the charge is sustained. This may be effected by connecting it with the ground or with the coating of another jar, which will thus also become charged, provided its exterior coating be uninsulated. A long series of insulated jars may thus be charged from each other, provided the opposing electricity of the last be withdrawn: and we thus obtain a polar arrangement through glass of a precisely similar nature to that which we formerly obtained through air, but of a much higher degree of intensity.(47)

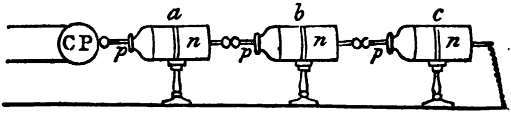


A polar arrangement of three jars is here shown, in which the extremity, P, of the prime conductor is positively electrified.

(47) Let *b* be a Leyden jar standing upon the glass support *a*. It will receive no charge from the prime conductor unless a deducting communication be made with its outside coating and the earth. If an uninsulated second jar be placed at *c*, the electricity which passes off from the outside coating of *b* will charge *c*, and for every spark which passes from the prime conductor to *b*, a similar one will pass from *b* to *c*.

If a very small jar be thus connected with a large one, the quantity of electricity which is sufficient to carry the charge of the first up to a high degree of intensity, when diffused over the larger surface of the second, will scarcely be appreciable; so that it will require many charges of the former to charge the latter to the same degree. This is the principle of Mr. Harris's *unit jar*. Instead of transmitting the electricity evolved by the machine immediately from its conductor to a large jar or battery, he communicates the charge from the outer coating of a small jar furnished with a discharging rod, by which the distance between its two coatings may be regulated and measured; and by the number of explosions, that is to say, by the number of charges which have passed from the smallar jar, the quantity accumulated in the battery may be very accurately estimated. By diminishing or increasing the distance between the discharging surfaces, the value of the unit may be varied at pleasure.(48)

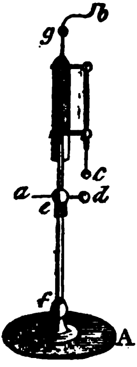
The balls, *p p p*, connecting with the interior coatings of the jars, *a b c*, are also positive, and the exterior coatings, *n n n*, the last of which discharges its positive electricity to the ground, are negative; or, it should be rather said, that the opposite surfaces of the glass with which they are respectively in contact are in these opposite states.



(48) The Unit Jar is represented on next page, mounted upon an insulating stand, *f*. A communication is made with the prime conductor of the machine and the exterior coating by the wire *g b*, and the interior coating is connected with the interior coating of the jar to be charged by the wire *a d*. The value of the unit of measure is determined by the distance between the balls *c* and *d*, or the striking distance of the spark. The effect of a spark from *c* to *d* is to neutralize the coatings of the unit

§ 227. In the usual construction of the Leyden jar or battery, the stem or wire by which the charge is communicated to the interior coating is left attached to it; the consequence is, that the induction does not take place solely through the glass to the opposite coating, but is partly directed through the air to surrounding conductors; this portion has commonly been called *free charge.* It is only, however, so far free as that it is not supported by the particles of the glass between the metallic coatings, but by those of the air intervening between one coating and surrounding objects. When a charged jar is insulated, this free charge may be removed from the interior by contact with a conducting body, when a corresponding portion of free charge of the opposite kind will make its appearance upon the outside coating, owing to the induction which will now be at liberty to direct itself from that part to surrounding objects. By successive alternate contacts, the whole of the charge may ultimately be removed, and the glass return to its natural condition.

The exterior conducting communication may be so contrived that it may be removed after the charge has been communicated, and then the induction will be determined entirely through the glass, and the charge on one side will be sustained by an exactly equal quantity of the contrary electricity on the other. All interference of surrounding objects being thus cut off, the jar will retain its charge for an indefinite period.



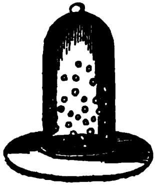
jar, and to distribute a corresponding quantity of electricity over the surface of the large jar. On giving a second charge to the unit jar, the large jar receives an increment equal to what it received from the first charge, and the second spark only neutralizes the charge of the unit jar as before, &c.

. That the charge of the Leyden jar is d p[illegible]t entirely upon the dielectric glass, and n upon the conducting coating, is proved by construc ing a jar with moveable conductors. If such a apparatus be charged, the interior lining may b lifted out by an insulating handle, and the jar itsel raised from its exterior metallic case, and still th charge will remain. In this case the superfici rows of particles on both sides of the dielectric become charged by the intervention of the met plates, and retain that charge after they are removed; those on one side being in the opposite stat to those on the other, and the immediate particle in a polar state. The only use of the coatings is t furnish a ready means of communication betwee the charged particles, by which the opposite force may be neutralized at the same moment when th circuit is completed between them. Without th coatings, the jar may be discharged, as it were piecemeal; but, upon replacing them, the discharg will take place in the usual instantaneous way.

Neither are the coatings absolutely necessary t the charge of a glass plate. If a clean dry glass ja be held over an electrified metallic rod, the point o which is brought opposite different parts of its su face, it will become charged; and if metallic coa ings be then applied, it may be discharged at once or, if it be placed upon a metallic plate, over som pith-balls or other light substances, they will be attracted and repelled backward and forward, and effect the discharge of the electricity, which induce from the interior towards the plate. They wil then remain at rest; but if the electricity, which ha now been disengaged upon the outside towards surrounding objects, be removed by a touch of th hand, a fresh portion will be set free on the interior, and the attraction and repulsion of the ball will again take place; and thus, for many times suc cessively, the action will be renewed until the glass returns to its natural state.(49)

§ 229. The discharge of a Leyden jar or battery may take place quietly through a conductor of electricity. This *conductive* mode of discharge involves no chymical action or displacement of the particles of the conductor. It may make its way forcibly through insulators and less perfect conductors. In this case the discharge is apparent, producing a dense bright spark, and is said to be *disruptive.* When the discharge takes place from a good conductor to one less perfect, the light may take the form of a brush, and finally, under some circumstances, the discharge may be slow, exhibiting a steady but faint luminous appearance or glow. The latter mode of discharge is always attended with a current in the air, or any other fluid medium which may be present.

§ 230. Even in the best conductors, the passage of electricity is resisted. Thus: the substance of a wire may be so reduced, or the quantity of electricity so augmented, that the metal may be fused by the great heat evolved, and scattered about with violence; and the resistance may even be sufficient to stop a portion of the charge. To produce this effect, it matters not whether the quantity employed be diffused over a large or a small surface, or what its original intensity may be, the same quantity will always fuse the same length of wire. Thus, if we measure a certain quantity of electricity into a Leyden jar by the unit jar, so that the electrometer may indicate a high degree of tension, and measure the same quantity into a large battery, where the electrometer will exhibit



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(49) An electrified bell-jar is here represented, placed upon a metallic plate, and the pith-balls in their state of alternate attraction and repulsion.

a very low degree of repulsion, the effects upon a wire through which the two charges may be directed will be precisely equal. The intensity, in fact, in the wire, which is insufficient to carry the whole charge in either case, rises to the same degree.

§ 231. As the expansive force of the discharge is manifested even in good conductors by the fusion and dispersion of metallic wires of insufficient thickness, so may it be exhibited with equal or greater violence in bad conductors, by a variety of experiments.

Place a card or some leaves of a book against the outer coating of a Leyden jar; put one extremity of a discharging rod against the card, and bring the other extremity to the knob of the jar; the charge will pass through the paper and perforate it, producing a small bur or protrusion on the side next the rod, and a larger bur on the side which was in contact with the coating.

Drill two holes in the ends of a piece of wood half an inch long and a quarter of an inch thick; insert two wires in the holes, so that the ends within the wood may be rather less than a quarter of an inch distant from each other: pass a strong charge through the wires, and the wood will be split with violence. Loaf-sugar, stones, and many other substances may be broken in the same way.

Insert two wires through corks in the opposite ends of a glass tube; let the distance of the ends of the wires be about half an inch: fill the tube with water, and pass a charge through it; the tube will be broken, and the water dispersed.

§ 232. The short duration of the spark discharge is proved by the velocity with which its light passes away; its duration not being sufficient to illuminate two successive objects, or the same object in two positions, whatever may be the velocity of their motions. It will be seen (§ 377) that when a disc painted with the prismatic colours is made to rotate very rapidly in common light before the eye the distinction of colours is lost, and an impression of white light is produced. [illegible] a broad black cross upon it [illegible] same manner, the cross [illegible] pears of a uniform [illegible] the flash of the [illegible] distinct, and the [illegible] stationary.

§ 233. By a [illegible] Professor [illegible] due) has [illegible] demonstrated that the [illegible] does not [illegible] Let us imagine a [illegible] with a hundred [illegible] each of them made [illegible] times in a second [illegible] obtained [illegible] be seen in the [illegible] their appearance [illegible] duration [illegible] flection will present [illegible] the appearance [illegible] of the same [illegible] rays [illegible] with a [illegible] of each [illegible] till [illegible] duration [illegible] a [illegible] corresponding [illegible] and [illegible] fifth [illegible] of light [illegible] wheel [illegible] created [illegible] subdivision [illegible] ing the number of [illegible] of the rotation, the necessity of judging by the eye of the relation of the illuminated to the dark spaces may be obviated, and the whole may be reduced to a determination of the velocity at which the complete illuminated circle is produced.

§ 234. Although variations in the density of the air produce no changes in the inductive capacity of the dielectric, the distance at which spark discharge may take place through it is greatly modified by its condensation or rarefaction. If two brass balls be placed within the receiver of an airpump so contrived that their distance may be altered by passing the stem of the upper one through a collar of leathers, and if one of them be connected with the conductor of the electrical machine, it will be found that, as the air is exhausted, the distance through which the spark will strike may be greatly increased, and the tension of the charge will diminish, as shown by an electrometer upon the conductor. The intensity, in fact, of a charged surface varies with the number of the particles of the dielectric over which its influence is diffused, and these depend upon the density of the medium, the form of the conductors, and the distances at which they are placed from each other. The rarefaction produced by heat acts in the same way as mechanical rarefaction; hence flame, which is incandescent air, offers an easy passage to an electric charge; and in all electrical experiments its influence should be guarded against.

§ 235. Dr. Faraday also found that, independent of their density, different kinds of aeriform matter were capable of sustaining different degrees of tension. He constructed an apparatus in which an electric discharge could be made along either of two separate channels; the one passing through a receiver filled with the gas which was to be the subject of the experiment, and the other having atmospheric air interposed. By varying the length

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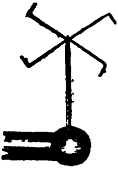
A continuous [illegible]

gives the glow; an interrupted one produces the brush; and, in a more exalted condition, the spark.

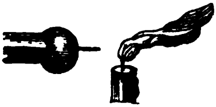
§ 237. Light models fitted up with vanes, like the floats of a water-wheel, may be put in motion by the current of air produced by the action of an electrified point; and if a lighted taper be presented to such a current, its flame will sometimes be blown out.(50)

If a point be enclosed in a glass tube so that it may be placed at any distance from one of the open ends of the tube, its influence as a point will be destroyed, and it will transmit electricity by sparks as a ball. The access of fresh uncharged air is thus stopped, and the process of convection cannot proceed.

§ 238. The light which accompanies the disruptive discharge of the electrical forces is accompanied by heat, and is capable of ingniting inflammable substances, such as ether, rosin, &c.; but its duration is so momentary, that sometimes it fails to produce this effect. If a little loose gunpowder be placed in a break between two wires, and a discharge be made through it, the grains will generally be scattered about without explosion; but if the electrical force be first made to traverse a portion of water or other imperfect conductor, it will, in its discharge, inflame the powder. This difference seems to be accounted for by supposing that the course of the electricity is retarded, so that it has time to produce



(50) This figure represents a light cross of wire, turning upon a point placed upon the prime conductor. The air is forcibly driven from the points, and, by its reaction, impels the vane in the opposite direction.



The flame of a taper is here represented under the influence of the air, passing off from a point upon a charged electrified conductor.

the effect which [illegible] more than [illegible] [illegible] [illegible] a good conductor would [illegible] [illegible] [illegible] [illegible] [illegible]. The light and heat which [illegible] [illegible] [illegible] [illegible] the discharge of the electric [illegible] [illegible] [illegible] [illegible] [illegible] among the polarized particles of a [illegible] [illegible] are probably perfectly analogous to [illegible] [illegible] [illegible] and heat which are produced by the [illegible] [illegible] [illegible] same forces, in a much lower degree of [illegible], among the particles of a good conductor whose substance is insufficient to effect their complete neutralization.

§ 239. At a very early period of electrical science, the identity of the electric spark and lightning was suspected; for Dr. Wall, in 1708, in contemplating the light and crackling noise produced by the friction of a large piece of amber, was led to remark that this crackling and light may be supposed in some degree to represent thunder and lightning. But it was Franklin who, in 1747, established the close analogy of the two agents by strict inductive reasoning, and experimentally verified his conclusions by imitating, on a small scale, the awful phenomena of nature. He had also devised the *crucial experiment* of drawing electricity from the clouds, by means of an insulated pointed rod of metal, for the erection of which he only waited the completion of a church steeple in Philadelphia. But M. Dalibard, in France, preceded him by about a month in obtaining the actual result, by repeatedly charging a Leyden jar by means of a similar apparatus during the passage of a thunder-cloud. Without any knowledge of this experiment, it occurred to Franklin, while occupied with the subject, that by means of a common schoolboy's kite, he might obtain ready access to the region of the clouds. He watched the opportunity of an approaching storm and went into the fields; and, with the assistance of his son, raised the kite into the air. He confined it by two or three feet of silken riband, but a considerable time elapsed without any result. One very promising cloud passed over his head without producing any effect upon his simple apparatus, when, being about to give up the attempt in despair, he observed, after a sharp shower, some loose threads of the string to repel one another; on this he fastened a key to the string, and was gratified by drawing an electric spark from it. He afterward raised an insulated metallic rod from the end of the house, so arranged as to communicate with two bells by means of a pendulum, which, striking against them as they were alternately attracted and repelled, warned him of the passage of an electric cloud.(51.)

The experiment with the kite has often since been repeated, with the addition of a thin copper wire twisted with the string; but it is not unaccompanied with danger, for experimenters have frequently received violent shocks, and the electricity has been known to discharge itself to the ground in sparks ten feet long and two or three inches in diameter. A fatal catastrophe from incautious experiments upon atmospheric electricity occurred to Professor Richman, of St. Petersburg, in 1753. He had erected an apparatus in the air, and was examining it with a friend, when a flash of lightning passed from the insulating rod through his body, and instant death was the consequence. His com-

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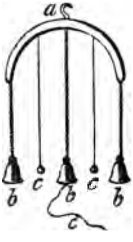

(51) The chime of bells here represented is suspended to the electrified body by the metallic hook, *a*. The two exterior bells, *b b*, are in metallic communication with it, and the centre one is insulated by a silk thread, but it is in metallic communication with the ground by the chain, *c*. The metallic clappers, *c c*, are suspended by silk threads; and, when the exterior bells are charged, they are alternately attracted and repelled, and discharge the electricity by convection to the centre conducting bell.

panion was at the same time struck senseless to the ground.

§ 240. The snapping noise which the electric spark makes in passing through a portion of the atmosphere, is due to the sudden compression of the air; and there can be no doubt that the awful thunder-clap is produced by the same action. The report is in this extreme instance modified by a variety of circumstances, such as distance, echo, &c.; and the sudden dying away and return of the sound may be accounted for on well-known principles.

We have already stated (§ 12) that sound travels in air with a velocity of only 1130 feet in a second, but light at the rate of 195,000 miles in the same period of time (§ 365). The time in which the flash of lightning reaches us, from the different points of its course, may therefore be taken as instantaneous; but the time which the explosion occupies will be very appreciable, and will vary with the distance of the several parts of the long line which the discharge traverses. By a calculation founded upon the interval between the flash and the sound, and the duration of the thunder-clap, it has been found that a flash of lightning frequently traverses a space of nine or ten miles; and, when we take into account the zigzag path which it ordinarily follows, its alternate approach and recession will account for the phenomenon in question. Such would be the effect produced upon an observer placed at the end of a long file of soldiers, who were to discharge their muskets at the same moment. He would not hear a single report, but a succession of reports, which would produce an irregular rolling sound.(52)

§ 241. If a house stand in the way of an electric discharge, that is to say, if it form by induction from the charged clouds a part of that line of particles which have attained the highest degree of tension, the course which the lightning will take will be determined by the accidental position of different conducting bodies within it, which will change the line

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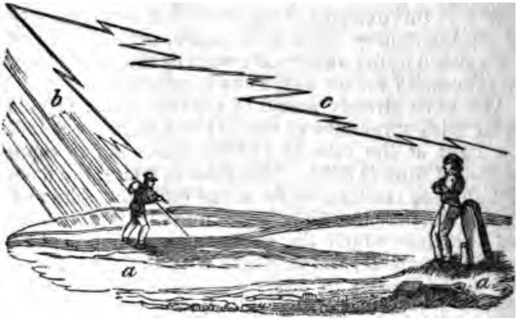
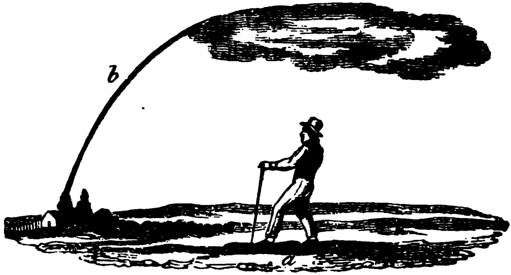
(52) The usual zigzag path of a flash of lightning is represented on the following page. The sound will reach the ob-

servers, placed at *a* and *a*, from the different points, in very unequal times, and will sometimes recede and then approach alter-



nately, as it reaches them from the farther or nearer portions of the atmosphere in which the concussion is produced.



Sometimes the discharge follows a path approaching to a segment of a circle; and then, if the observer be placed in a situation nearly equidistant from every part of the flash, it will affect him with a single crash.

of greatest tension according to their relative situations. Thus it is probable that it may descend a chimney in which the air is rarefied; or it may strike the same object from being the most elevated conducting body in its course. It may then leap to different metallic articles in the chambers, or even to persons whose good conducting properties may present an easy transit in the position in which they may be placed; it will finally pass to the earth, after having thus followed the path which had been previously determined by the arrangement of the particles under the highest state of inductive influence. As long as the discharge is confined to the good conducting substance of metals, lightning produces no injurious effects; but, whenever it passes from these into imperfect conductors, its course is marked by destruction.

§ 242. To Dr. Franklin belongs the honour of having suggested the application of the known principles of electrical science to the defence of buildings against the dangers of a thunder-storm. He proposed the erection of a continuous metallic rod in perfect communication with the earth, by the side of any building intended to be secured against the effects of lightning; and experience has fully demonstrated the utility of this precaution. The great points to be attended to in the construction of such conductors are, that they should be carried above the highest point of the building to be protected; that they should be of sufficient substance not to be melted; and the experience of a century has proved that a copper rod of half an inch diameter has never yet been fused; that there should be good metallic contact in all their parts; and that they should terminate at a sufficient depth in the ground, and be led, if possible, into some piece of moist earth or large body of water. It has been proved that conductors erected with these precautions will protect a circular space of a radius double their height above the highest point of the building to which they a attached.

§ 243. An objection, founded in ignorance, h sometimes been made to lightning-rods, that th may, by their attractive power, invite a dischar where otherwise it would not have taken plac But when it is considered that one of the conditio of a thunder-storm is an intense electrical inducti of a portion of the earth's surface through a d stratum of air to the surface of a cloud of so thousands of acres in extent, in the manner of Leyden jar, it will be perceived that any such el vation, as compared with the distance and extent the charged clouds, is utterly inconsiderable, a perfectly inadequate to influence the charge in t slightest degree. The conductor is perfectly pas ive, and its efficacy consists in opening an ea path by which the force may be transmitted. I action is at best but of a negative kind, and it c no more be said to attract the lightning than a w ter-course can be said to attract the water which n cessarily flows through it at the time of heavy rai

It is true that a pointed conductor will silent draw off a considerable portion of the electric char from a distant cloud, and this action will sometim be indicated by a glow, or even brush, upon its e tremity; but this would tend to diminish the state tension of the charged masses; and if inadequa to produce an appreciable diminution of the en mous quantities collected, can have no influence exalting the tension to the point of disruption.

§ 244. The beautiful meteor called the *aurora l realis*, there can be little doubt, is another form electrical discharge taking place in the upper regio of the atmosphere, where the decreased density the air admits of those brushes and coruscatio which can be so well imitated in the receiver of t airpump. Luminous brushes, aigrettes, and glo have not unfrequently been observed also, previo o thunder-storms, upon the mastheads of vessels, he points of soldiers' spears, and even upon the utstretched fingers of the hand. Upon the high able-land of Mexico, where the atmosphere at times s extremely dry, the horses' manes become luminous and emit a crackling noise. These lights used ormerly to be regarded with feelings of dread and uperstition, and went in Italy by the name of the Fire of St. Elmo.

§ 245. The atmosphere, though not usually charged to the excess which is necessary to produce the phenomena to which we have just adverted, will commonly afford indications of electrical excitement. In calm, dry weather, when no clouds are visible, the gold leaves of an electrometer, armed with a pointed rod or flame, will always indicate vitreous electricity; and it has been ascertained that its intensity is subject to regular variations, reaching a maximum about seven or eight o'clock in the morning, and falling to a minimum between one and two. In high winds and damp weather, without rain, electrical indications can rarely be obtained; and in cloudy weather, and in times of showers of hail, rain, or snow, they vary very much both as to kind and intensity.

§ 246. We have hitherto directed our attention principally to one method of exciting the electrical forces, namely, the friction of dissimilar substances, by which their particles are rapidly brought into close contact and as rapidly separated. By this operation we have found particularly that the rubbed surface of a dielectric becomes inductive; its charge being sustained both through its own substance and through the air to surrounding conductors. But there are many other methods by which this extraordinary agent may be developed; and, indeed, the forcible disturbance of the established equilibrium of the particles of bodies in any way seems sufficient to call it forth in various degrees. Thus the forcible disruption of cohesion; mere pressure upon certain crystallized substances; the heating of others; changes of physical state; crystallization and evaporation, are all capable of producing electrical excitement.

§ 247. If we break a roll of sulphur, we shall find a charge of electricity upon its two fresh surfaces; and if we pound it in a dry mortar, and pour the fragments upon the glass of an electrometer, the leaves will diverge very forcibly; and if we renew the contact with fresh surfaces upon a fresh plate, we shall find that it is not easy to deprive it of the whole quantity which it has thus acquired.

If we take a rhombohedron of Iceland spar, and, holding it by two opposite edges, press upon two of its opposite faces, it will manifest a decided power of attraction upon light substances.

§ 248. Crystals of tourmaline, again, whose optical properties will be described (§ 392), exhibit a very remarkable state of electrical excitement when gently heated. The tourmaline is a hard, crystallized mineral, which occurs in granite and other primitive rocks, in the form of three, six, or nine sided prisms, terminated by three or six sided pyramids. It was discovered by the Dutch in Ceylon, who called it *Aschen trikker*, from its property of attracting ashes when thrown into the fire. It appears, however, to have been known to Theophrastus. When the stone is of considerable size and warmed, flashes of light may be seen to dart across its surface when laid upon a hot iron. If a crystal of this mineral be mounted upon a pivot, or otherwise suspended with freedom of motion, its excitement will be found to be polar, and one end will be attracted by excited glass and the other repelled. The polar arrangement of its particles exists throughout its substance; for, when broken in two, each half will prove to be likewise polar. It is during the rise of its temperature that these phenomena take place: during the process of cooling they also occur, but with the opposite direction of the forces.

The poles of the mineral have reference to the axis of symmetry, and those crystals are alone electrical, the opposite extremity of whose axes differ with regard to the number, disposition, and figure of their facets.

§ 349. Boracite is another mineral which possesses the property of becoming electric by heat in a high degree. It crystallizes in the form of a cube, but the edges and angles are generally replaced by secondary planes, and four of the angles are always observed to present a greater number of facets than the other four: the most complex angles are rendered vitreous, and the simplest resinous, by heat, and these are always found at the opposite extremities of the axis of symmetry.

§ 250. Electricity may also be developed by the near contact of heterogeneous substances. Thus, if a circular disk of platinum be fitted with an insulating handle, and pressed against a similar disk of zinc, both being held by the insulating rods, both will be electrified, as may be rendered manifest by the condenser and gold-leaf electrometer. The zinc will have vitreous, and the platinum resinous electricity. Silver or copper may be used instead of platinum, and like effects, although in a less degree, will be apparent.

§ 251. If melted sulphur be poured into a glass vessel, it becomes electrical in the process of crystallization; and if it be removed from the glass and examined after solidification, it will be found in the resinous state, and the glass in the corresponding vitreous state. Water, also, in the act of freezing, becomes electrical.

The evaporation of water likewise excites electricity; and if a heated platinum vessel be placed upon the cap of a gold-leaf electrometer, and water dropped into it as the steam flies off, the leaves will expand with resinous electricity. The effect is rendered very decided with the assistance of the condenser. The late experiments of M. Pouillet have rendered it probable that the evaporation of perfectly pure water is not accompanied by any development of the electrical forces, but that a very minute portion of saline matter in solution is sufficient to determine the effect. This does not detract from the probability of evaporation, being the principal source of atmospheric electricity; for all the water upon the face of the globe is impregnated more or less with different salts. The vitreous electricity that corresponds to the resinous charge, which, in the experiment, is left upon the electrometer, is carried into the air, and probably communicates a charge to the minute drops into which it is again condensed, and which float in the atmosphere.

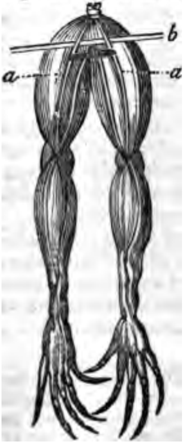
GALVANIC ELECTRICITY.

§ 252. The phenomenon we have just cited is made the basis of a method of developing a modification of electricity, far more important in its action and in its connexion with other branches of physical science than that which is excited by friction.

The history of the origin of this most important branch of science must, almost necessarily, be included in their description. In the year 1790, Professor Galvani, of Bologna, was accidentally occupied with the dissection of a frog, at the time when some other person was experimenting with an electrical machine in its neighbourhood, and observed that, whenever the point of his scalpel was in contact with one of the crural nerves, and a spark was drawn from the machine, violent convulsions were occasioned in the limbs.

We now know that, under these circumstances, the frog formed part of a system of bodies under induction, by the polarization of the particles of which, the charge was sustained upon the prime conductor; when the latter was discharged, their state of tension was relieved, and, in returning to their former state, commotion was produced similar to that which takes place with more violence when an animal is placed in the course of the discharge of a Leyden jar. In seeking to vary the circumstances of the experiment, the explanation of which was unknown to him, Galvani armed the muscles and the nerves with different metals, and found that, whenever a metallic communication was made between the two, similar convulsive movements were produced without the co-operation of the electrical machine.(53) The new branch of science which sprang from this capital observation has been called Galvanism, in honour of the mind which discerned the importance of phenomena of such apparently trifling import.

§ 253. There are many ways now known of varying the experiment. By placing a live flounder upon a slip of zinc, with a shilling upon its back, whenever a metallic communication is made between the two metals by a metallic wire, strong muscular contractions are produced in the fish. If a piece of silver be placed upon a person's tongue, and a piece of zinc



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(53) This figure represents the legs of a frog prepared for galvanic experiments. The skin is removed, and the crural nerves, *a a*, are easily found by gently separating the muscles on the back of the thighs: *b* is a silver wire passed under both the nerves, by which metallic contact is ensured. The legs may be laid upon a plate of zinc; and, when the circuit is completed by a metallic communication between the two metals, violent convulsions are produced.

or lead under it, no effect will be observed as long as the two metals are kept apart; but when their ends are brought in contact, a slight sensation, as from a feeble electric shock, will be produced, and a peculiar saline taste. If one metal be placed between the upper lip and the gums, upon bringing their ends together as before, the eyes will be affected as by a flash of light. This observation had been made nearly fifty years prior to Galvani's by Sulzer, but excited little attention; although, perhaps, it exhibited the germe of the future science in a more striking form; showing what different fruits are produced by accidental seeds when they fall upon a mental soil unprepared for their reception, and upon one fitted by proper culture.

§ 254. In these experiments, no effects are observed from separate pieces of metal of the same kind, and the contractions are most powerful when those metals which are most difficultly acted upon by acids are opposed to others which are easily acted upon.

§ 255. The apparatus by which the most powerful galvanic effects are produced, was the invention of Professor Volta, of Pavia, whose name it perpetuates. He was led to this grand discovery by a series of experiments which he undertook, to prove that the agent in Galvani's experiments is common electricity, which he endeavoured to accumulate by a multiplication of his simple circuit.

§ 256. Its first form was that of a pile, in which pairs of zinc and silver discs were placed one above another, each pair being separated from the adjoining by pieces of cloth, rather smaller than the plates, moistened with a solution of common salt.(54)

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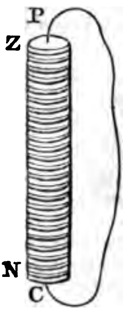
(54) The original Voltaic pile was composed of silver coins and zinc discs of the same size, piled up in the manner shown on the opposite page, with paper moistened with a saline solution, or a dilute acid, placed between each pair. When the fingers of one hand, well moistened with salt and water, are

Great care was taken to preserve a regular order in the position of the metals; so that if the zinc were placed below the silver in the first pair, the same order should be preserved in the others. Another form, which Volta denominated "The Crown of Cups," consisted in a row of small glasses, arranged in a circle, containing dilute sulphuric acid, or a solution of salt, in each of which was placed a plate or wire of silver or copper, and one of zinc, not touching each other, but so connected that the zinc of the first was in contact with the silver of the second, and the zinc of the second with the silver of the third, and so on throughout the series.(55) In this arrangement it could be seen



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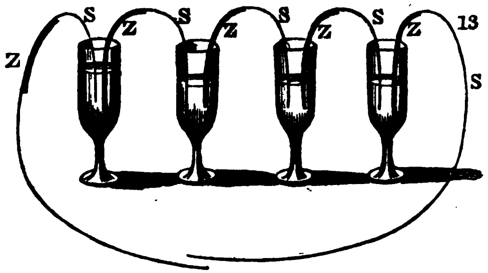
placed in contact with c, and the fingers of the other hand with p, a slight shock is felt, and a spark may be perceived upon making contact between the two extremities with a wire or piece of charcoal.

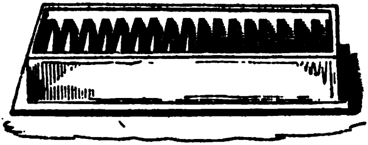
(55) Volta's "Couronne des tassas" is here depicted. Wires of silver and zinc, S and Z, are soldered together in pairs, and alternately placed in the glasses containing dilute acid. No action takes place till the extreme wires S and Z are brought into communication by means of a metallic wire, when each silver wire is seen to evolve hydrogen.



that no current action took place till the extreme wires were brought into contact. Various other forms were gradually introduced by Cruickshank, Babington, and Wollaston, as experience suggested improvements.(56)

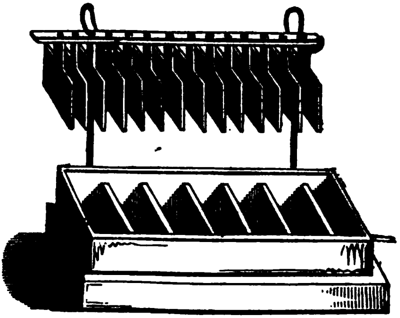
(56) The inconvenience of the original construction of the pile was in some degree obviated by Mr. Cruickshank, who cemented the pairs of plates into a well-seasoned wooden trough, as in figure 1. The intervening spaces were filled with the proper liquid for exciting the battery.

Fig. 1.



The arrangement was still farther improved by Dr. Babington, who soldered the plates of copper and zinc together in pairs by one point only, and fixed them upon a rod of wood, by which

Fig. 2.



they could be lifted together, in convenient numbers, into or out of a trough of earthenware, divided by partitions into cells for their reception (figure 2). The fluid may thus be allowed

§ 257. In Volta's view of the phenomena, the source of electricity was the contact of the dissimilar metals. When two metals, the most dissimilar in regard to their attraction for oxygen, are insulated, and made to touch each other, and again separated, the most oxydizable will be found to be in a state of vitreous excitation, and the least in the opposite state. We have already seen (§ 207), that if a plate of metal be placed upon the cap of a gold-leaf electrometer, and zinc filings be sifted upon it through a copper sieve held by a glass handle, the leaves will diverge with vitreous electricity, and the

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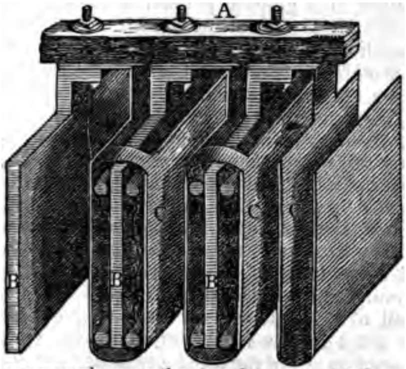
to remain in the trough, while the action may at any time be suspended by raising the plates from the cells, and placing them upon rods fixed for their support.

The improvement of Dr. Wollaston consisted in extending the copper plate so as to oppose it to both surfaces of the zinc, as shown in figure 3. A represents the bar of wood to which the

Fig. 3.



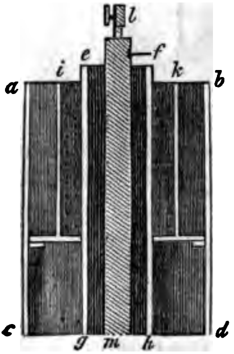
plates are screwed; B B B the zinc plates, connected, as before, with the copper plates C C, which are doubled over the zinc plates. Contact of the surfaces is prevented by pieces of wood or cork placed between them.

sieve will be found in a resinous state. With a zinc sieve and copper filings, the electrical changes will be reversed. If we arrange the metals in the following order, which is that of their affinity for oxygen, each will become resinous by the contact of that which precedes it, and vitreous by the contact of that which follows it, and the greatest effect will be produced by the contact of the most distant metals of the series: potassium, zinc, lead, tin, iron, copper, mercury, silver, gold, platinum. The interposed liquid was regarded by the inventor of the pile merely in the light of an imperfect conductor, which allowed of the accumulation of the electrical fluids, disengaged by the electro-motive power of the metals, by a species of inductive influence. Others, again, maintain that the electricity is wholly due to a chymical action.

§ 258. The liquid employed in the voltaic batteries, when it has been desired to excite them to the utmost, has generally been a mixture of sulphuric and nitric acids diluted with water; in which case much local action takes place upon the zinc plates, which contributes nothing to the force which circulates, and which speedily destroys them. Their power, moreover, speedily declines by the deoxydation of the oxyde of zinc upon the copper plates, and they are very inconstant in their action.

These defects are obviated in the construction of the *constant battery*, the contrivance of Professor Daniell, of London, which consists of a series of single circuits, constructed upon the principle of a central disposition of the active metal with regard to the conducting surface.

A cell of this battery consists of a cylinder of copper 3 1-2 inches in diameter, which experience has proved to afford the most advantageous distance between the generating and conducting surfaces, but which may vary in height according to the power which it is wished to obtain. A membraneous tube, formed of the gullet of an ox, is hung in the centre by a collar and circular copper plate resting upon a rim placed near the top of the cylinder; and in this is suspended, by a wooden crossbar, a cylindrical rod of amalgamated zinc half an inch in diameter. The cell is charged with a mixture of eight parts of water and one of oil of vitriol which has been saturated with sulphate of copper; and portions of the solid salt are placed upon the upper copper plate, which is perforated like a colander for the purpose of keeping the solution always in a state of saturation. The internal tube is filled with the same acid mixture without the copper. A tube of porous earthenware may be substituted for the membrane with great convenience, but probably with some little loss of power. A number of such cells admit of being connected together very readily into a compound circuit, and will maintain a perfectly equal and steady current for many hours together, with a power far beyond that which can be produced by any other arrangement of a similar quantity of the metals.(57)



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(57) One of the cells of the constant battery is here represented. *a b c d* is a copper cylinder, in which is placed a smaller cylinder of porous earthenware. Upon the upper part of the copper cylinder rests a perforated colander, *i k*, through which the earthenware cylinder passes. *l m* is a cast rod of amalgamated zinc, resting upon the top of the interior cylinder by a crosspiece of wood, and forming the axis of the arrangement. The cell is charged by pouring into the earthenware cylinder water acidulated with one eighth part of its bulk of oil of vitriol, the space between the earthenware tube

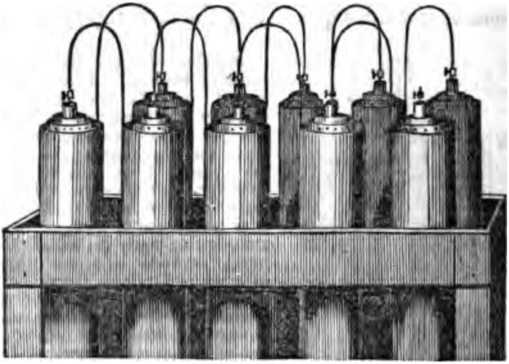
§ 259. We have noticed that heat generally increases the affinity of substances for each other, as manifested in their local action; it has an analogous influence upon galvanic action. When a constant battery of nine cells, which was capable of decomposing water at the rate of 7.5 cubic inches of the mixed gases per five minutes, was enclosed in a case to which steam could be admitted, the rate of working gradually increased with the temperature, till at 212° it was very nearly trebled.

Changes of atmospheric temperature even have a marked influence upon the workings of the voltaic battery, and must not be neglected in nice comparative experiments.

§ 260. In the galvanic apparatus, both chymical and electrical effects are produced. That one of

and the copper being filled with the same acidulated water saturated with sulphate of copper; and solid sulphate of copper being placed in the colander.

A number of such cells may be connected into a compound



circuit, by wires attached to the copper cylinders, and fastened to the zinc by clamps and screws, as shown above.

the active bodies should be a good conductor of electricity, and the other a liquid compound, are essential conditions of the circulation of galvanic electricity: the first, that the force may readily diffuse itself upon every point of its surface; and the second, that the necessary transfer may take place. In the excitement of electricity by the friction of dissimilar substances, the contact is broken and renewed, with successive particles, by a kind of intermitting action, and by the rapid mechanical separation of the two bodies their charge may be communicated to other bodies in a manner which has been already explained. In its excitement by chymical action fresh articles are also brought into contact in continuous succession, while those which are spent or neutralized are successively removed in combination by the action of concurring forces.

§ 261. In both cases the charge is sustained and communicated by induction, or the polarization of the particles of matter, which must always precede and accompany conduction. When an extensive voltaic series of some hundreds of couples of perfectly clean plates is simply charged with distilled water (which is so bad a conductor of electricity as to allow a disruptive discharge through it in the form of a spark), it is clearly shown that induction takes place in it of precisely the same nature as that which arises from electricity by friction, for each extremity will exhibit a charge of electricity sustained by the induction of the air to surrounding conductors, and which may be manifested by the usual attractions and repulsions, and even sparks, by which we recognise electricity from friction. It will be found that, under these circumstances, the zinc extremity of the battery possesses a vitreous, and the copper extremity a resinous charge.

§ 262. The amount of this effect of high intensity does not at all depend upon the size of the plates, but is proportionate to the number of alternations.

A battery constructed of pieces of copper tube 3-8ths of an inch in diameter, and 2 1-2 inches long, with a piece of zinc wire of 1-8th of an inch in diameter soldered to each, and turned down into the axis of the next without metallic contact, and consisting of a series of 1024, will be quite equal to a battery of the same number of plates four inches square, and capable of producing all the effects which we are about to describe.

A gold-leaf electrometer, placed in connexion with either end, will open out with either electricity, as has just been stated; and if, at the same time, the electricity of the opposite end be discharged, the leaves will expand still farther, as in all analogous cases of common electric charge. When the two ends are connected severally with an insulated slip of gold leaf, upon gradually approaching the two they will attract each other, and a spark will pass between them. By moistening the hands and touching the two extreme cells, a slight shock is also experienced.

§ 263. These effects may be very much increased by a more advantageous arrangement of the terminal surfaces: thus, if one of the ends of the battery be connected with the insulated plate of a condenser, the latter will instantly become charged, and when the opposite plate is withdrawn, the electrometer will indicate a much higher degree of intensity. The charge may also be sustained through glass, and transferred to the metallic surface of the Leyden battery. If wires proceeding from each extremity of the series be respectively connected with the inner and outer surface of an electrical battery, of not less than 12 square feet of coated surface, it will be charged so rapidly that sparks may be obtained from it in rapid succession by connecting a fine wire with its outer surface, and successively *striking* the knob with its other extremity. The *fine point* of a penknife or thin metallic leaves may thus be burned, phosphorus inflamed, and fulminating powders exploded. No such power is possessed by the voltaic arrangement alone; but it communicates the charge to the battery so instantly that almost continuous discharges may be procured. The intensity is limited to that which is due to the number of the series, but the extent of surface which may be thus thrown into inductive action is unlimited. When the human body is made the medium of communication between the surfaces of a large battery thus perpetually charged, the rapidly intermitting shock which is received is very unpleasant.

§ 264. The polarity of the voltaic arrangement is also shown by breaking the series at any part, when each portion will exhibit a resinous and vitreous extremity, just as in breaking a magnet each fragment exhibits a north and south pole.

These effects are, of course, annihilated by bringing the opposite ends of the series into metallic communication; but no continuous current of any amount takes place when the circuit is closed. When the extremities are connected with platinum wires, dipping into water even acidulated with sulphuric acid, no decomposition is manifested, however numerous the series may be; but a slight decomposition is shown when a solution of iodide of potassium is made the medium of communication.

§ 265. The electric column of De Luc presents these polar phenomena in a very striking form. It consists of pairs of very thin silver and zinc discs not more than 5-8ths of an inch in diameter, piled up in regular order, with the intervention of writing-paper, to the number of some thousands. They may be formed of strongly gilt paper and zinc foil, cut out with a punch, and enclosed in a glass tube fitted with brass caps at each end, and carrying screws, by which they can be pressed together. If the paper be dried artificially, the column will be inactive, but its ordinary hygrometric moisture will be sufficient to throw it into a strong polar state. A series of 2000 or 3000 is sufficient to affect the gold-leaf electrometer, and one of 20,000 will cause pith-balls of 1-5th of an inch diameter, suspended by threads of four inches long, to diverge to the distance of two inches and upward.(58) By connecting one extremity of the series with a fine iron wire, and drawing its point lightly over the other extremity, a slight layer of varnish being interposed, a series of minute sparks may be obtained. A Leyden battery may also be charged by it, so as to occasion a disagreeable shock to be felt distinctly in the elbows and shoulders.

This apparatus will retain its power for years if kept in a state of insulation, but loses it if the ends are allowed to be connected together for any length of time. No current, however, is established under these circumstances which can be detected by any chymical decomposition.

§ 266. It may, perhaps, be doubted whether the source of the electric charge of this instrument is the contact of the metals, or the contact of the zinc

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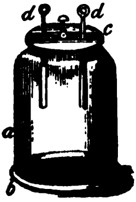
(58) When De Luc's column is placed with each end in connexion with a gold-leaf electrometer as here represented, one of the instruments will diverge with vitreous, and the other with resinous electricity. When the electricity of either end is discharged by a good conducting communication with the ground, the opposite force is exalted, and the divergence of the leaves increases; and, when a metallic communication is made between the two ends, all signs of electricity cease.

with the small portion of moisture which is contained in the paper in its common hygrometric state. When the paper has been artificially dried, it is found to be inefficient, as has been already stated, and the zinc becomes slowly corroded in the course of years; but, on the other hand, the charge is wholly one of intensity, and, after its discharge, requires an interval of time for its renewal.

§ 267. Now this state of polarity is manifested precisely to the same degree, dependant upon the number of the series, when the voltaic battery is charged with dilute acid instead of pure water. The particles of the liquid, as well as of the solids, are thrown into a similar state of tension, which is only relieved by a good conducting communication between the two extreme poles. The difference of the effects may be well shown by connecting the two poles of such a charged battery with insulated strips of gold leaf, when, upon approximating them as before, they will attract each other; but, instead of the neutralization of the charge by a mere spark, a rush of electricity will burn, and utterly disperse the metal, which is insufficient for its transmission.(59) This strong current makes its way through the liquid portion of each cell by a new species of convection, of which the polar arrangement is the antecedent condition.

§ 268. Every part of the wire which forms a connexion betwen the two poles of a voltaic battery, is capable of exerting a powerful action upon the mag-



(59) The experiment may be performed with the electrometer here represented. *a* is a glass shade mounted upon a base, *b*. It is covered with a piece of dry varnished wood, *c*, in which the glass tubes, *d d*, slide backward and forward, and through which pass wires having gold leaves suspended to their lower extremities. The distance of the gold leaves may be accurately adjusted by a rack and pinion.

netic needle. If the needle be allowed to tak natural position under the directive power oi earth, and the wire be placed above it in a paı direction, the end which points to the north l directed towards the silver plate, that end will ı towards the west, and the needle will tend to ı itself across the wire: but if the wire be pl below the needle, the same pole will move eastv and cross the wire in the opposite direction. V the position of the zinc and platinum plates, regard to the needle, is reversed, the directio the movement of the needle will be also reveı and its ultimate position will indicate the cours the current.(60)

This is not the place in which we propose t quire into the laws of this magnetic action; only at present brought forward to demonstrate, the wire which connects the two metallic plat the arrangement which has been described, do reality transmit a force which manifests itsel very energetic actions. It has also been applie the construction of a very delicate instrument measuring the quantities of galvanic electricity

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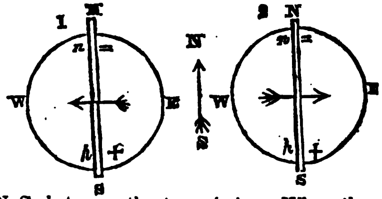
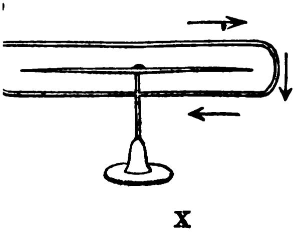
(60) In the annexed diagram, let *p n* represent the condu wire of the circuit, *n* being in connexion with the silver and *p* with the zinc plate. Let the natural direction c needle, under the influence of the earth, be represented b



arrow, N S, between the two circles. When the neec placed above the wire, 1, its marked pole will be deflect wards the west, and when placed below the wire, 2, it w deflected to the east.

9. Every point of the connecting wire equally
ices the magnetic needle, and the force with
it affects it may be doubled by bending it
pon itself, and placing the needle between its
arallel branches.(61) If a copper wire be
nto a rectangular form, consisting of several
uarded from metallic contact by being cover-
h silk, and in the centre of the rectangle a
ely suspended needle be placed, each coil will
influence to that of the others, and the needle
impelled by the joint action of all. If such
ingement, previous to its connexion with the
plates, be placed so that the rectangular coils
allel to the needle in the position it occupies
the directive influence of the earth, and the
xion be then made, the effect will be to occa-
ich a deviation from the plane of the magnetic
an as will arise from the balance between
w force acting on it and the magnetic force
earth. The number of degrees at which the
stops, measured upon a graduated arc of a
will therefore give an approximative measure
intensity of the force exerted by the wire.

'his figure represents a magnetic needle, freely support-
a point within a rectangle, formed by a wire doubled
d placed in connexion with the zinc and copper plates
cuit, by the mercury cups, P and N. By this arrange-
ment the influence of the under part of the conducting wire is doubled upon the needle: for both the parallel lengths conspire to deflect it from its natural position in the same direction, and to bring it into a position nearer to a right angle to the plane of the wire.



We are not prepared at present to describe the several modes by which the force may be determined with perfect accuracy.

§ 270. An instrument constructed in the manner which we have described is called a *Galvanometer.* Its delicacy may be very much increased by employing two needles attached together, one above the other, in a parallel direction, with their poles in opposite directions. The distance between the needles is such as to allow of the upper part of the coil of wires to pass between them; an opening being left by the separation of the wires at the middle of the coil for allowing the thread by which they are suspended to hang between them. By this contrivance, the directive power of the earth upon the *astatic needle*, as it is called, is very nearly neutralized, enough only being allowed to remain to bring it to a constant direction when the wire is in a state of inactivity: at the same time, when thrown into action, both the needles are impelled in the same direction. The lower needle being in the situation of the more simple apparatus just described, is acted upon by the forces in every part of the coil, while the upper needle is impelled by the contrary influence of the upper side of the wire, but in the same direction as the lower, on account of the reversed position of its poles.

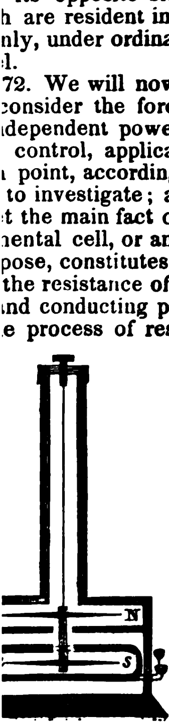
The needle of an instrument so constructed will be sensibly deflected by the immersion of less than 1-8th inch of zinc wire, 1-50th inch diameter, and a corresponding length of platinum wire, in a large drop of water acidulated with sulphuric acid.

The galvanometer may be rendered a still more accurate measure by completely neutralizing the influence of the earth upon the astatic needle, and substituting the force of torsion to produce the equilibrium with the force of the active wire. The ease and accuracy with which the former may be

ured, renders it a very perfect means of esti-
ıg the amount of the latter.(62)

71. Every part of a wire, thus forming a communication between a zinc and platinum plate imed without contact in the same vessel of aciduwater, whatever the metal may be, is endued its opposite sides with the opposite forces h are resident in the magnet, and communicanly, under ordinary circumstances, to iron and ·l.

72. We will now turn from the battery itself, consider the force which is thus generated as ıdependent power, over which we have comcontrol, applicable to certain work at any ı point, according to laws which we will proto investigate; at the same time, we must not ·t the main fact of circulation, and that the exıental cell, or any other object which we may pose, constitutes, in reality, a part of the cirthe resistance of which rests upon every other ınd conducting portion of the arrangements.
.e process of resolving a compound body into



(62) The torsion galvanometer of Dr. Ritchie is here represented. s s is the lower needle, surrounded by the coil of wire, and connected with the upper needle, S N, by a piece of straw, which passes through the upper part of the horizontal coil, and through a circular card placed above it, on which a graduated circle is drawn. It is then attached to the torsion filament, which is fixed to a screw, supported by the frame of the instrument. The filament may be of glass, and the angle of torsion may easily be measured upon the graduated card. The wires of the coil are easily connected with the plates of the circuit by means of the small mercury cups,

its elements, or proximate principles, by the voltaic current, has been named *electrolysis*, and substances which are capable of such decomposition are called *electrolytes.*

In electrolysis, a current is conceived to pass from the positive or vitreous to the negative or resinous pole. These are called by Farraday the *zincode* and *platinode*. The term *electrode* is common to both. The surface of the body to be decomposed, at which the current enters from the zincode, is called by him the *accode*, the other surface the *cathode*. At the former, the acids, oxygen, chlorine, &c., are evolved; at the latter, hydrogen, the metals, alkalis, &c. The easiest case of electrolysis is that of water. If this liquid be confined by corks in a tube, through which iron wires proceeding from the zincode and platinode of a battery are passed, the zincode wire will be rapidly converted into oxyde, and a stream of oxygen will rise from the platinode.

By using wires of platinum or gold instead of iron, oxygen will rise from the zincode, and hydrogen will continue to appear at the platinode. These two gases will, if the tube be straight, be capable of being exploded by a spark of common electricity, and reconverted into water.

By the use of a bent tube the gases may be collected separately into its two branches, and it will be apparent that their relative bulks are 2 : 1.

When the water is slightly acidulated, the action of electrolysis is promoted, and with a more powerful arrangement of plates, the acid will itself be decomposed. The decomposition of the acid will also take place when it is unmixed with water. Thus: if sulphuric acid be subjected to the action of a battery, oxygen will appear at the zincode, and crystallized sulphur at the platinode; when nitric acid is acted upon, oxygen is evolved at the zincode, and nitrogen at the platinode. When the alkaline salts are exposed to galvanic electricity, the acid is carried to the zincode, and the alkali to the platinode. The presence of these two forms of compounds may be exhibited by performing the experiment in a bent tube upon a solution coloured by a vegetable blue. This will be changed at the zincode to red, and at the platinode to green.

The same fact may be exhibited by placing the solution, coloured as before, in two vessels which are united by a siphon, which is filled with the same solution. The communication between these vessels may be made by a moistened bladder, or by amianthus, and the results will be the same.

If three cups be used instead of two, an acid or an alkaline salt may be placed in the middle one. When an acid is thus placed, the alkali will be carried through it to the *zincode;* and if the middle cup contain an alkali, the acid of the salt will traverse it in its way to the platinode.

§ 273. One essential condition of electrolysis is liquidity; the elements of a compound cannot travel when restrained by cohesion; and, with very rare exceptions, compound bodies cannot transmit the current except by electrolysis.

If one of the outer cells of a powerful battery be separated from the other in water, by a film of ice not more than one sixteenth of an inch in thickness, there will not be the slightest galvanic effect; but if a small portion be thawed, so as to form the thinnest possible film of water between the two, the needle will be permanently deflected.

A great variety of both primary and secondary combinations are subject to the same law. On fusing a little chloride of lead in a glass capsule by a spirit lamp, and introducing it into two platinum wires connected with the poles of the battery, powerful action will take place, and the chloride will be rapidly decomposed. On removing the lamp, the *instant the chloride* solidifies, all current and contemporaneous effects will cease, though the platinum wires may remain enclosed in the chloride not more than the one sixteenth of an inch apart. Chloride of silver, nitrate of potassa, and chlorate of potassa, act exactly in the same way; and, in every case, decomposition of the compound takes place when the current passes.

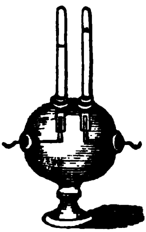
With regard to the substances on which conducting power is conferred by liquefaction, the degree of power so given is generally very great. Water is that body in which this acquired power is the feeblest; in the various other oxydes, chlorides, salts, &c., it is some hundred times greater. A greatly increased conducting power is given to water by the addition of salts. The addition of other liquids and soluble solids, as sulphuric acid and boracic acid, which by themselves are not capable of electrolysis, and, consequently, are non-conductors, confer this increased power upon water. Even some elementary substances exalt its conducting power, and a solution of chlorine will convey the current much more readily than pure water.

§ 274. The next point which must arrest our attention is the definite direction which the disengaged elements or principles are forced to take under the influence of the current.

In the cells of the battery, the oxygen of the decomposing water, from its natural affinity, must travel from the conducting plate towards the zinc, and the hydrogen in the opposite direction; and in the experimental cell which forms part of the circuit, the two gases must move in conformity with these directions; and hence the oxygen will, as we have seen, be evolved at the zincode, and the hydrogen at the platinode. The elements or principles of any other electrolyte which comes under the government of the current will be subject to the same law of direction; and those elements which, in the order of common affinity, have the greatest attraction for the zinc, will take the path of the oxygen, and appear at the zincode, and their associates must travel in the opposite course, and escape at the platinode. Thus, among the elementary substances, chlorine, iodine, bromine, and fluorine, range with oxygen, and the metals with hydrogen; and among the proximate principles, cyanogen and acids rank with the former, and alkalies and protoxydes generally with the latter.

§ 275. The invariable nature of these relations may be well exhibited by placing several electrolytes in different cells, and including them in one circuit with a battery of sufficient power. Thus: place solutions of chloride of sodium, coloured with indigo; iodide, and bromide of potassium, mixed with starch; and sulphate of soda, coloured with a vegetable blue, in succession in four siphon tubes, reversed, and connect them together and with the battery by platinum electrodes; the first will be bleached at the zincode by the evolution of chlorine; the second coloured blue at the corresponding electrode by free iodine; the third will become deep yellow with the bromine disengaged at the same point; while the indications of free acid and alkali will be manifested respectively at the zincode and platinode of the fourth.(63)

Fig. 1.



(63) Some of the forms of apparatus in which these processes of electrolysis may be conducted, are here represented.

Figure 1 is a glass vessel with two orifices, each having a tube adapted to it in such a way as to receive the separate gases from the two platinum electrodes, which pass into globes filled with acidulated water.

Figure 2, represented on the next page, is a cell made of plates of glass, cemented together, and divided into two parts by the temporary diaphragm, *a*, which consists of a small frame of wood, with muslin stretched over it. A separate electrode may be introduced into each side of it, and the products of the decomposition may thus be kept separate for a time and examined.

§ 278. The disruptive discharge of the
battery through air is dependant upon the
principles as that of the Leyden battery; l
phenomena are modified by the lower int
greater quantity, and perpetual renewal of the
When passing between two charcoal points,
ration renders it the most splendid source
which is under the command of art. Rare
of the medium through which it passes, eit
heat or by mechanical means, produces the
effects as upon the common electric spar
friction. When the poles of a powerful batt
gradually separated after contact, the dis
takes place through an interval which in
with the heating of the air by the ignited ch
With the original battery of the Royal Ins
of 2000 plates, the discharge passed throu
inches of air; and with the constant batter
cells, the flame is much more voluminous,
tends to the distance of one inch.

It would, however, appear, that the air is
only form of matter which is concerned in t

Figure 3 exhibits two glasses, connected together by
of large bore, filled with an electrolyte, and two tubes
in the glasses and filled with the same liquid; into t
ends of which platinum wires, terminating in long sli

Fig. 2.

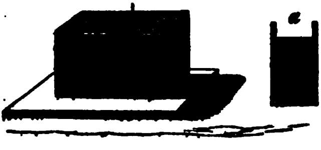
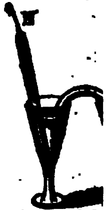


Fig.



same metal, are inserted. The opposite products of th
position may thus be separately obtained; the conve
rent passing through the interposed liquid in the sipho

nomena, but that particles of the solid electrodes contribute to the general effect by convection. It is probable that the superior brilliancy of the phenomena with charcoal may be owing to the larger number of its solid particles which its small cohesion enables it to throw off in the process.(64)

§ 277. In some experiments with a large battery constructed by Dr. Hare, the platinode was made of plumbago, and the zincode of well-burned charcoal; a most vivid discharge was produced, and fused particles of the plumbago were transferred to the opposite pole, which sensibly increased in length.

In other experiments which were lately made by Professor Daniell with a constant battery of 70 large cells, a great body of flame was generated, which passed through a distance of about an inch, and the charcoal of the zincode invariably presented a cup-shaped cavity, while a considerable protuberance was formed upon the platinode of hard and brilliant carbon with a mammillated appearance. When the zincode was of platinum, and the platinode of char-

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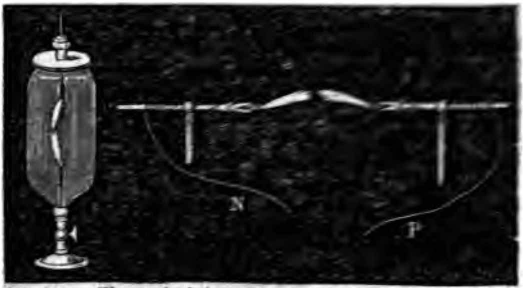
(64) Some notion of the appearance of the voltaic flame both in the air and in vacuo, may be formed from the annexed



sketches. The arched form is owing to the ascensional force of the heated air.

coal, the latter became studded with globules of fused platinum; and when this arrangement was reversed, a considerable protuberance of carbon was formed upon the platinum platinode.

§ 278. The colour of the light varies with the substances between which the discharge passes. The beautiful effects produced by the deflagration of thin metallic leaves interposed in the course of the discharge are not owing to the combustion of the metals, though in some cases increased by this cause, but arise from a dispersion of their particles analogous to that of the more momentary explosion of the Leyden battery. They equally, in both cases, take place in vacuo.

Gold leaf emits a white light tinged with blue; silver, a beautiful emerald green light; copper, a bluish white light with red sparks; lead, a purple; and zinc, a brilliant white light fringed with red.

The disruptive discharge of the voltaic battery will take place with great brilliancy under the surface of distilled water; some electrolytic effect will at the same time occur, but the greater part of the charge will pass in a brilliant stream of light.

THERMO-ELECTRICITY.

§ 279. We have seen that when the electric current meets with obstruction to its course, the equilibrium of heat is disturbed even in good conductors; it might, therefore, have been *a priori* expected that a disturbance in the equal flow of heat would produce an electric current, in such forms of matter as are capable of transmitting it.

We are indebted to Professor Seebeck, of Berlin, for the experimental confirmation of this conclusion in 1832, and the discovery of the phenomena of THERMO-ELECTRICITY.

§ 280. If a platinum wire be carefully soldered to the two extremities of a delicate galvanometer, and it be heated at any point remote from the junctions, no disturbance of the electric equilibrium will be produced; from the homogeneous structure of the wire, the heat will flow equally to the right and left of the heated point. But it will be very different if a knot or spiral turn be made in the wire without breaking it: for if the focus of heat be applied to the right of such obstruction, an electrical current will be established from right to left, and will be indicated by the needle. This must arise from the unequal rate at which the heat will obviously be propagated on two sides of the obstructing mass. Wires of copper and silver will act in the same way, only in a very inferior degree. The same effect will be produced if the wire, instead of being continuous, be divided, and each end being twisted into a spiral to increase the surfaces, one be heated red in a spirit lamp, and brought into contact with the other. The deviation of the magnetic needle will indicate, as before, that a current is passing from the hotter to the colder point. That these effects do not depend upon any chymical action of the air, is proved by performing the experiment under the surface of well-purified oil, under which circumstances the same results will be obtained.

Those metals which possess a decidedly crystalline texture, present even more marked electrical phenomena from the unequal propagation of heat in their masses. If a ring or rectangle be cast of antimony or bismuth, of the diameter of three or four inches, and of the substance of about the third of an inch, and one half of its surface be kept cool by ice and the other heated, a current of electricity will be immediately established of sufficient power to affect the magnetic needle without the assistance of a coil.

§ 281. These thermo-electric effects, again, are very much increased by combinations of two metals. If a bar of antimony have a copper wire soldered to it, or merely twisted round one of its ends, and attached to the other in the form of a loop when heated at the contact of the metals at one extremity, it will strongly deflect a magnetic needle placed above or below it.(65)

It is found that similar circuits may be formed of combinations of other metals, and that they may be ranged in the following order according to their thermo-electric efficiency; the most powerful combination being formed by those metals which are the most distant from each other in the series: bismuth, platinum, lead, tin, copper, or silver, zinc, iron, antimony. When heated together, the current is found to proceed from those which stand first to the last.

§ 282. There can be little doubt that the specific heat and conducting power of the metals must be concerned in these effects; but, in comparing the tables of each, the connexion does not immediately appear. Structure or crystalline arrangement has also much influence upon them. With some combinations, as, for example, zinc and silver, the current will go on increasing with the temperature to a certain point, 248°; will then become null, and, by increasing the heat, will be re-established in the contrary direction. This singular phenomenon is most probably referrible to a change in the arrangement of the particles of the zinc.

§ 283. Similar circuits may also be formed, according to the experiments of M. Nobili, with substances whose conducting power is lower than that of the metals. He made small cylinders of porcelain clay, of the length of three or four inches, and three or four lines in diameter, and wrapped round

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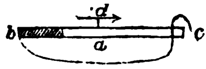
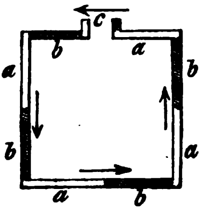
(65) *a* represents a bar of antimony with a piece of copper wire twisted round one end of it, *b*, and looped over the other end, *c*. When heated by the flame of a spirit-lamp at the contact of the metals, *b*, a magnetic needle placed at *d* will be deflected.



the ends of each some cotton steeped in a conducting liquid, which served to place them in direct communication with the galvanometer. One of the ends was reduced to a point, and, after heating it red at a spirit-lamp, he pressed it upon the cold extremity of the other cylinder, and a current was established from the hot part of the arrangement towards the cold. This effect is owing to the mutual reaction of two portions of water of different temperatures.

§ 284. The thermo-electric current may be increased by forming a compound circuit, and arranging the pairs of metals in a series of alternations analogous to those of the voltaic pile. If three bars of bismuth, with three of antimony placed alternately, so as to form the sides of a hexagon, be soldered together and placed upon two supports in a horizontal position, one of the sides being in the magnetic meridian with a compass-needle below it, upon heating one of the junctions, the needle will be sensibly affected. The deviation will be considerably increased on heating two of the alternate angles of the hexagon; and a still greater deviation will be produced when the heat is applied to the three alternate angles.

In all these combinations, similar effects may be produced by reducing the temperature of one or more of the junctions by the application of ice or other means; and when the action of ice, on one set of the alternate angles, is combined with that of the flame on the other set, the effect is still more considerable.(66) Upon multiplying still farther



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(66) *a a a a* represent four bars of antimony soldered to four bars of bismuth, *b b b b*. If the extremities at *c* be placed in perfect metallic communication, as by the wires of a galva-

the number of alternations, it is, however, found that the total effect is inferior to the sum of the effects which the same elements could produce when employed in the formation of simple circuits. This is owing to the low state of intensity of the current, which occasions great loss of power whenever it has to traverse any considerable line of conductors even of the most perfect kind.

§ 285. The thermo-electric pile has lately been applied by Messrs. Nobili and Melloni, as a most delicate and accurate measure of temperature. Thirty-six pairs of bars of bismuth and antimony, packed into a small compass, and having a very delicate galvanometer with two needles attached to them, were found to be so sensible as to be affected by the warmth of the hand at the distance of thirty feet; and an instrument constructed upon this principle, with all the necessary precautions, is applicable to a variety of delicate investigations, for which any of the common thermometers would be totally insufficient.

§ 286. The thermo-electric current will occasion convulsions in the limbs of a frog, but is inadequate in its primary state to effect any kind of chymical decomposition.

§ 287. There is another well-established and remarkable effect of the heating power of the voltaic current, which is as yet unexplained. When the conducting wires from the two extremities of a powerful battery cross one another, and are brought in contact, upon separating them to a short distance a flame will appear between the two, and the zincode or electrode connected with the conducting plate of the battery will become red-hot, and that con-

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nometer, and the temperature of the junctions be alternately raised and depressed, an electric current will be determined in the direction of the arrows; which will cause the deflection of a magnetic needle placed immediately over or under any part of the circuit.

nected with the generating metal will remain dark, and comparatively cool. This effect is constant, of whatever metal the conducting wires may be made.

§ 288. The power of fusion by the electrical flame is greatly influenced by this circumstance, and metals laid upon charcoal, in connexion with the zincode, melt much more rapidly when the flame is directed upon them from the platinode, than when their situation is reversed. The constant battery of 70 cells before referred to, completely fused the most refractory metals when thus disposed; and platinum, rhodium, titanium, and iridium, were melted in considerable quantities.

§ 289. At a very early period it had been observed, that when vessels at sea had been struck with lightning, their compasses were often destroyed; and that, in some instances, their property of pointing north and south had been destroyed, or the poles reversed. Dr. Franklin succeeded in imitating this by frequent discharges of the electrical battery. We have also seen in the experiments which have served as the basis of the construction of the galvanometer, how powerfully the forces of electricity and magnetism act mutually on each other. We are therefore now led to the consideration of the last-named force.

MAGNETISM.

§ 290. The force of magnetism has already been spoken of (§ 15), as it resides in the loadstone, or as it is communicated from that mineral by friction to bars of steel. The polarity of a magnetical bar, or its property of pointing towards the north, has long been used in navigation. It is even said that the Chinese and Arabians, who were acquainted with this directive power before the Europeans, employed it as long ago as 1000 years before the Christian era. This property of the magnet is mentioned in a Chinese dictionary finished in A.D. 121;

and in another dictionary, published in the reign of Kanghi, it is stated that under the Tsin dynasty (previous to A.D. 419), ships even steered to the south by the magnet.

The navigators of Amalfi, in Italy, appear to have received the compass from the Arabs during the Crusades; and it was universally used in the times of Columbus and Vasco de Gama.

§ 291. Let us now examine the phenomena with more precision.

If a long bar magnet be covered with iron filings, and then withdrawn from the heap, it will be found that a portion of the filings adhere to its surface, but in a very unequal manner: large clusters will be suspended from the two extremities, but not a particle will be attached to the centre between them.(67) It may also be observed that long filaments, composed of many smaller ones joined end to end, will stand erect from the ends; but that, as they recede from these points, they will be shorter and shorter, and incline from each other, appearing to be self-repelled. The best mode of examining the attractive points of such a bar is to place it under a sheet of paper, upon which iron filings may be sifted. By gently tapping the paper, they are slightly projected into the air, and, as they fall under the

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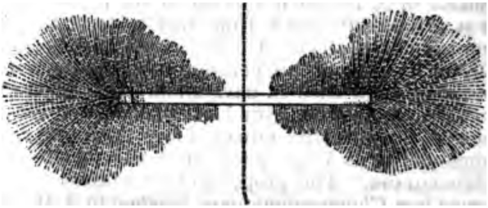
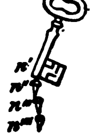
(67) If a magnetized bar be placed on a sheet of paper, and iron filings be sifted upon it, they will adhere to it in the manner here represented.



influence of the magnetic attractions, they distribute themselves into regular and beautiful curve lines, which converge towards the extremities, where they are collected in largest quantities. These points of attraction are the poles of the magnet: that is, points endued with similar, but opposed, forces of attraction and repulsion, analogous to those which we found in an insulated electrical conductor under induction. A needle of soft iron, freely suspended from a silk thread, will be attracted precisely in the same way as the iron filings; but a magnetic needle of steel will be attracted by one extremity, and repelled by the other. These phenomena take place through interposed metals, glass, resins, water, paper, &c., and are clearly distinguished from their analogous electrical attractions and repulsions.

§ 292. Sometimes a bar which has been magnetized to saturation will present points which have been called consecutive poles, indicating alternation of the two magnetic forces. These may be discovered by the grouping together of iron filings, or by the alternate attractions and repulsions of the bar at the different points when freely suspended.

§ 293. Soft iron becomes magnetic by induction from a magnet, just as an insulated cylinder of metal becomes electrical by the action of an electrified body through the air. If a key or other piece of iron be held near one of the poles of a powerful loadstone or magnet, it will be found that a series of iron balls and needles may be suspended from it, each in succession becoming polar under the influence of the inducting force.(68)



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(68) A represents a bar magnet, near to the marked extremity of which, N, a key is held: this will become magnetic by induction, and will induce magnetism upon the three small nails brought near it, which will be consequently attracted. The positions of the marked

When the magnet is withdrawn, they all immediately return to their neutral state.

The opposition of the poles may be well shown by suspending two small iron cylinders, side by side, in contact, and approaching them with the pole of a magnet; each will become temporarily magnetic, and each will have its nearest end converted into an opposite pole to that of the magnet: the similar poles of the two cylinders will consequently be in contact, but will immediately repel each other, and the cylinders will fly apart.(69)

If a quantity of fine iron wire be cut into lengths of about one eighth of an inch, large quantities of it may be suspended from a magnet.

§ 294. The magnet, like the charged electrical conductor, loses none of its original force while communicating this induced power; but, on the contrary, it has its own state exalted by the reaction of the opposite power it thus develops.

§ 295. There is, however an essential difference

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poles of these temporary magnets are indicated by the letters n'' n''' n''''; when the key is gradually removed from the influence of the magnet, the iron nails successively fall off.

Fig. 1.

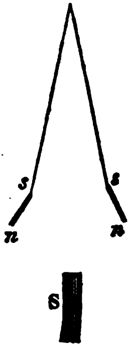
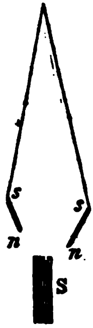


Fig. 2.



(69) When the unmarked pole of a magnet, s, is held at a little distance from two pieces of soft iron, suspended from a point by two pieces of thread (figure 1), they both become magnetic by induction, and the two similar poles, n n, and the opposite poles, s s, repel one another. If the pole of the magnet, s, (figure 2) be approached nearer to them, its superior attraction will overcome the mutual repulsion of the poles, n n, and they will be drawn towards it, but the poles, s s, will separate to a greater distance than before.

in the character of electrical and magnetical induction: we have seen (§ 214) that, if a cylinder under electrical induction be broken in two, each half will retain an opposite charge independently of the other; but if, under similar circumstances of magnetic influence, an iron wire be cut in two, the end which is removed will show no signs of free magnetism. Under no circumstances, indeed, can one magnetic force be obtained in any form of iron without the co-existence of an equal amount of the opposite force in the same mass: and if we fracture a magnet or loadstone into any number of pieces, each fragment will be a perfect magnet with contrary poles.

§ 296. We may suppose a mass composed of minute grains of metal, each surrounded by a non-conducting substance not adding sensibly to its bulk: on bringing a body thus constituted near an electrified body, every one of the grains would immediately become electrical by induction; and it has been mathematically proved, that the attractions and repulsions which such a body would exert externally, would be the same as those of a homogeneous conductor of the same form and size, subjected to the same inductive influence. In the latter case, however, the two forces would be transferred to the opposite extremities of the body, while in the former they would remain in the masses to which they originally belonged. Such, in fact, appears to be the disposition of the electric forces in the tourmaline, and it offers an excellent illustration of the disposition of the forces in the magnet.

§ 297. Hence we may conclude that magnetic induction takes place in consequence of the complete and separate polarization of each particle of iron, and that the forces cannot travel from one to the other, to accumulate at the ends like the electric forces in an insulated conductor.

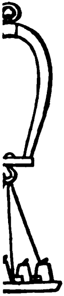
Iron filings, by their mere juxtaposition, under the influence of a magnet form a series of minute magnets, of which the poles are similarly situated in each: and, being alternately of different kinds, the adjacent ends attract one another. An accumulation of such filings, between the opposite poles of two magnets, or of a magnet bent in the form of a horseshoe, accurately represents a bar of soft iron placed in the same position, and the particles of both we conceive to be precisely in the same condition.

Separate magnetic charges cannot be supported by distant bodies by a polarization of the particles of the intervening air equivalent to that which maintains a charge of either of the electrical forces: The magnetic forces traverse all substances except iron and one other metal, nickel, without affording any indications of that action upon their particles which has so lately been established by Dr. Faraday in the case of the electrical forces.

§ 298. Perfectly pure soft iron returns immediately to its neutral state upon removing the inducing cause or pole of the magnet; but if the natural arrangement of the particles of the metal be disturbed by mechanical force, such as twisting or violent hammering, it will retain its polarity for longer or shorter periods. The new arrangements which take place from chymical combination also confer this retentive or coercive power in a high degree: hence the permanence of the magnetic forces in the loadstone, which is an oxyde of iron, and in hard steel, a compound of carbon and the same metal.

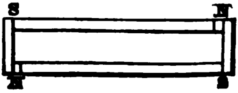
§ 299. The process of induction takes place very slowly in tempered steel by mere contact; the coercive power, which retains the particles in their polarized state, when once acquired, opposing itself to its reception: but it is greatly facilitated by friction. When one pole of a powerful magnet is rubbed two or three times along a bar from end to end, always ie same direction, the latter speedily acquires magnetic virtue. Various modes of friction been devised for saturating steel bars with netism; instead of the simple mode just indi- d, which goes by the name of the single touch, two opposite poles of a magnet, bent into the of a horseshoe,(70) may be brought down upon centre of the bar to be magnetized, with the s turned in a direction the reverse of that of poles intended to be given to the bar, and then ed backward and forward along the surface; ig care to pass over each half of it an equal ber of times, and repeating the same operation he opposite side. This is called the double h, and the bar becomes speedily and effectually netic.

300. Great advantage is derived, when two bars to be magnetized, by disposing them in a paral- ;ram, in conjunction with connecting pieces of iron. The bars are touched in the way just ribed, so as to have their dissimilar poles op- d; and, in proportion as they receive magnetism, e connecting pieces acquire a similar power, by their reaction tend to exalt the intensity of charge.(71) Horseshoe magnets, for the same



(70) This figure represents a magnet bent into the form of a horseshoe, by which means the two poles are brought near to each other, and are better adapted to many experiments. When not in use, they are connected together by a piece of soft iron, which is called the *keeper*, by which their force is preserved unimpaired. The power of a magnet may be measured by suspending a scale-pan to the keeper, and loading it with weights till it becomes detached by their gravity.

(71) This figure represents two bar magnets, with their opposite poles, N S, placed in juxtaposition, and connected by means ir armatures of soft iron.

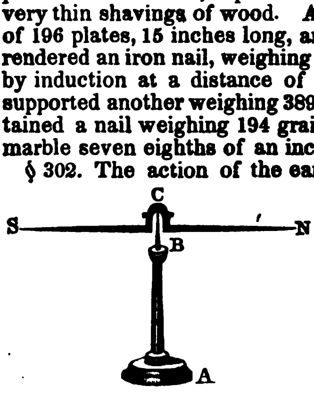


reason, may be most efficaciously touched by connecting together their extremities with soft iron. In such a complete circuit, moreover, the power is preserved most securely by the reciprocal influence of the opposed forces, and magnets, when out of use, should be carefully protected in this manner. While such a circuit is closed, it will exert but a feeble influence upon any exterior body; but the *keeper*, as the soft iron bar is called, is retained in its position by a very powerful attraction. It is, however, found that the weight which it will support immediately after the process of magnetizing is much greater than when the circuit is reclosed after having been once broken.

§ 301. Powerful magnetic batteries are constructed by uniting a number of horseshoe magnets, laying them one over the other, with all their poles similarly disposed, and fastening them together in a copper case.

Mr. Scoresby has lately ascertained that great advantage arises from constructing magnets of thin plates of hard steel, separated from one another by very thin shavings of wood. A magnet thus formed of 196 plates, 15 inches long, and 1 1-2 inches wide, rendered an iron nail, weighing 500 grains, magnetic by induction at a distance of 11 inches, so that it supported another weighing 389 grains. It also sustained a nail weighing 194 grains through a slab of marble seven eighths of an inch thick.

§ 302. The action of the earth upon a magnetic needle(72) may be

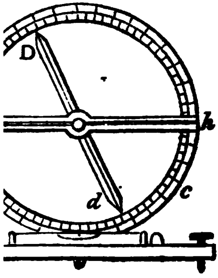


(72) This figure represents a convenient mode of supporting a needle for the purpose of indicating its direction. A is a stand in which is fixed an upright rod, of any substance but iron. The latter terminates in a point,

red to that of a large bar magnet upon it; ay be represented by the action of such a t passing nearly along the axis of a globe, les of which, however, do not exactly coinith the poles of the earth's rotation. If a magnetic needle, suspended so that it has n of motion in a vertical plane, be placed y upon such a magnet or upon the equator of be, it will assume a horizontal position, with es directed to the dissimilar poles of the ar.

end of a needle or bar, which directs itself s the north pole of the earth, is, for conve- , generally distinguished by a mark, and is re best denominated the marked end. It is mes called the north end or pole; but very erly, as it manifests the opposite force to that acts at the north terrestrial pole.

he needle above mentioned is advanced toone pole of the large magnet, the end which ted towards that pole begins to dip or incline ard, till at length it stands perpendicularly it. Upon being gradually drawn back to its position, it slowly recovers its horizontal on; and, upon being advanced towards the e pole, the same series of phenomena take vith the opposite end.(73)



which fits into a small agate cap at the centre of the needle, which is thus free to move with the least possible friction.

(73) The suspension of the dipping-needle is here shown. The needle is formed of a flat piece of steel, through the centre of which a small axis passes at right angles. It freely moves in circular holes, made in the horizontal bar, H *h*, which

§ 303. Perfectly analogous phenomena of direction and dip take place under the influence of terrestrial magnetism, but the laws which govern them are of a more complicated nature. A needle freely suspended, out of the influence of any ferruginous mass, only remains in equilibrium when in the magnetic meridian; there are places where this line coincides with the terrestrial meridian, and in these the magnetic needle points to the true north. If, however, it be carried successively to different places on the earth's surface, its direction will be sometimes to the east, and sometimes to the west of north. It appears, from the latest researches, to be probable that there may be more than one magnetic pole in either hemisphere. According to the observations of M. Hansteen, there is one in Siberia, in longitude 102° east of Greenwich, and a little to the north of the 60th degree of latitude; according to the calculations of Sabine, made in the same manner, and about the same time of those of Hansteen, the other pole is in lat. 60° N., long. 80° W. The magnetic equator, moreover, does not coincide with the terrestrial equator, but, from a discussion of all the observations, appears to be an irregular curve, crossing it in at least three points of longitude.

The direction of the needle varies even in the same place; in the middle of the 16th century, the needle in London inclined a few degrees to the eastward of the true north; in 1659 it pointed exactly north; and after this the line of no variation began to travel slowly westward, and has now passed over to North America. At New-York the variation, as observed by Professor Renwick, was 5° 28′ W. in 1837.

§ 304. The dip undergoes corresponding changes, though less considerable than those of the variation; and in London it has been found that there has been

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forms the diameter of the circle, c *c*, which is graduated for the purpose of showing the angle made by the needle with the horizon.

an annual diminution of about 3′ for the last fifty years. It is at present between 69° and 70°. By the determination of Sabine, the dip in New-York was 72° in 1822.

§ 305. The needle is also subject to diurnal variations of small amount; in our latitudes it moves slowly eastward during the forenoon, and returns to its mean position about ten in the evening. These variations doubtless depend upon diurnal changes of temperature.

Besides the variation and the dip, there is a third circumstance which is deserving attention, and that is the intensity of the force which obliges the needle to take up its position of equilibrium. This force varies greatly in different latitudes, and increases generally from the equator to the poles.

§ 306. For a long time, the only known means of estimating the intensity of the magnetic forces was to ascertain the weight which might be suspended from a magnet by means of a piece of soft iron. This, of course, is a very inaccurate operation; but Coulomb suggested two methods by which this important point may be determined with the greatest precision. The first of these is the torsion balance, the operation of which has already been described; and the second, the method of oscillations. This consists in counting the number of oscillations made by a magnetic needle in resuming its original position, under the influence of any magnetic force, when disturbed from its position of equilibrium. The movements of the needle are subject to the same laws which govern the oscillations of a pendulum acted on by the force of gravity; and it is a necessary consequence of these laws, that the intensity of the force producing the oscillations is proportional to the square of the number of oscillations performed in a given time.

By these methods it has been determined, that the forces both of magnetical attraction and repulsion are in inverse proportion to the square distances of the active bodies.

§ 307. The earth, thus regarded as a ma capable of acting by induction upon other and if in these latitudes we hold a bar of p iron in the direction of the magnetic dip, th end will have the properties of the marked a magnet, and the upper those of an unmark as may easily be ascertained by approachi with a magnetic needle. That this state of is only temporary, may be proved by rever bar, when the poles will be found in the san tion as before. A bar of steel or of hard i become permanently magnetic by remaining the same position, and it commonly happens fire-irons, poker, and tongs, which usually against the grate, in a position not very from that of the dip, become magnets.

§ 308. The communication of magnetism t bar by this influence may be greatly exped causing it to vibrate strongly, as by striking i in the proper position, upon the end with a h It may also be greatly increased by the in influence of other masses of iron in contact notwithstanding the iron itself, which thus the effect, derives its power also from th source, namely, the magnetism of the earth. a steel bar acquires a feeble magnetism b hammered vertically when resting upon s pewter, but receives a considerable acces power when subjected to the same degree mering while placed upon a parlour poker i ilar position. The power of a magnet is, always increased by the reaction of anothe in which it induces magnetism; and this p is made useful in *arming* (as it is termed) a loadstone, and thereby increasing its power plates of very soft iron are provided, e breadth to the surfaces of the stone which the poles, and a little longer; so that, when applied to them, a portion of each plate projects beyond the loadstone. The armature is fixed on very firmly by wires, or an external case of any metal not susceptible of magnetism. The power of the stone is found to be thus very much augmented.

§ 309. As the mechanical vibration of the particles of a steel bar facilitates its reception of magnetic polarity, so will the diminution of its coercive power by the same means promote its return to the neutral state, and highly-charged magnets quickly lose their virtue by any concussion of their particles. A fall on the floor, rubbing with coarse powder for the purpose of polishing, and grinding, will all prove more or less injurious to their powers.

§ 310. The only substance, besides iron and its compounds, which has been found susceptible of magnetic polarity, of the kind which we have just been considering, is the metal nickel; but there has been some difficulty in determining this point, from the small quantity of iron which is capable of conferring attractive powers upon other metals with which it may be alloyed. This, in some instances, is so small as to escape the detection of chymical analysis.

§ 311. The influence of heat upon magnetism is very remarkable. If a steel bar be heated to redness, and placed under magnetic induction, and then suddenly cooled, it will be found to have become strongly and permanently magnetic in a very short time. On the other hand, the application of heat to a magnet is invariably attended by a dissipation of its power. It is sensibly affected by the heat of boiling water; and a red heat totally destroys its magnetism. If the temperature, however, be raised only to 100, it loses much of its power during the operation, but recovers it again on becoming cool; but, after it has been heated to redness, no part of its magnetism returns. The power of a magnet, moreover, increases as it becomes colder, to the utmost limit to which refrigeration can be carried.

At a white heat, iron appears to be totally susceptible of any magnetic impression whatever, and a white-hot ball of iron may be brought close to a delicate magnetic needle without at all disturbing its state of repose. Nickel loses its magnetic influence at a much lower temperature, and becomes totally indifferent when heated to 630° Fahrenheit.(74)

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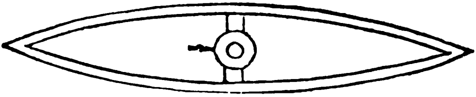
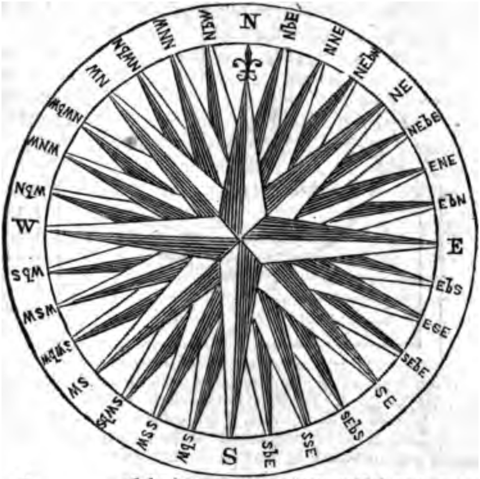
(74) The most important magnetic instrument is the Compass. Of this there are two varieties, the Mariner's and the Surveyor's. The essential part of both is a magnetized bar or needle, supported, as in figure 72, on a vertical point. The needle is made heavier at one end than at the other, in order to counteract the dip; and, when it is to be used in succession in different parts of the world, proper poise is effected by a moveable weight.

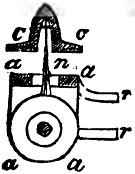
The form of needle which is now preferred is a modification of that proposed by Kater. His experiments showed a superiority in those made of four bars, united in the form of the sides of a rhomb. The same advantages exist in the modified form represented beneath, which is constructed by rounding the obtuse angles of the rhomb.



In the Mariner's Compass, the needle is attached to a circular card, which revolves or *traverses* with it. The outer circumference of the card is divided into 360 degrees. Within this is a circle divided into 32 equal parts, called *points* of the compass. Those which correspond with the two ends of the needle are called North and South. Those at right angles to them, East and West. These four are called cardinal points. The mode of naming the other points will be best understood by inspection of the figure. See *opposite.*

The axis on which the needle hangs rises from the bottom of a deep box, which is loaded with a heavy weight. This axis terminates in a steel point, which rests in an agate cup, *c c.* Beneath this cup is a ring, *a a*, which is moveable, and can, by means of the handle, *r r*, which is produced to the outside of the compass box, raise the needle from the pivot and prevent it from traversing. At two opposite points, near the upper surface

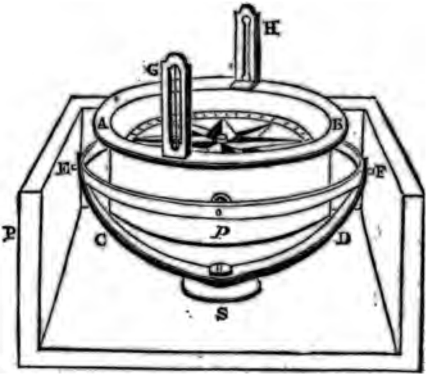




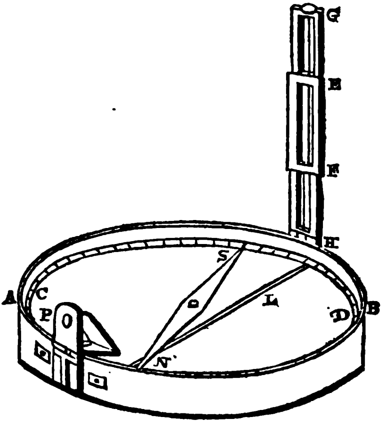
of the box, are two pivots, which rest on a circular ring. This ring has two pivots at right angles to the first two, which rest on an outer ring which is fixed. The weight of the box, thus hanging from two sets of pivots at right angles to each other, will keep the pivot on which the needle rests vertical. The arrangement will be understood from a reference to the first figure on the next page.

In the Surveyor's Compass the divisions are cut on a ring which surrounds the needle, and forms a part of the box which encloses it. The degrees are divided into four quadrants, which are numbered to the right and left from the N. and S. points.

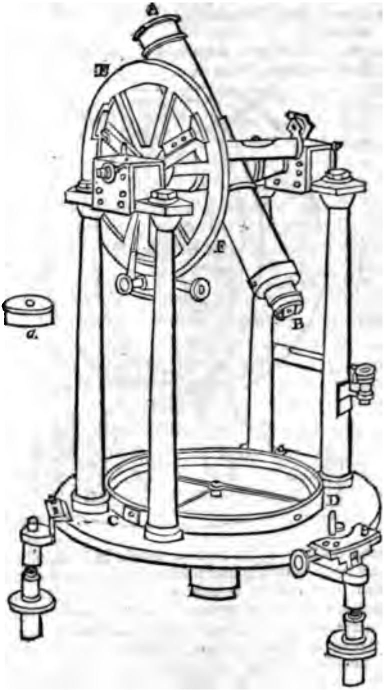
When a compass is fitted for the purpose of ascertaining the variation of the needle, it is called an Azimuth Compass, from an astronomic term which is used to denote the horizontal angle contained between the position of a body and the N. and S. point. If this angle be referred to the meridian, it is the true azimuth; but if to the N. and S. points of the needle, it is the magnetic azimuth: and the difference between these two angles is the variation. By placing sights on the upper surface of the



box which contains the angle, as represented in the pre figure, the magnetic azimuth is measured by directin sights to a heavenly body; and, if the hour of the day is the true azimuth can be calculated. A more convenient a compass was invented by Kater. In this the divisions

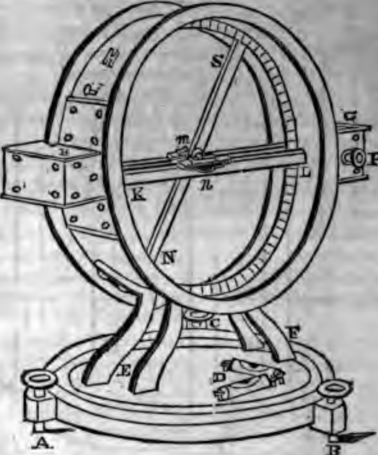


card are reflected by a surface placed at an angle of 45°, in a horizontal direction, so that the eye may see at the same time an object by direct vision, and a reflected view of the division immediately between the eye and the object. The divisions on the card are carried on from 0° to 360°, and are marked, the N point of the needle being marked S. Smalcalder's modification of this is more convenient than Kater's original form; and, in an instrument recently constructed in France by Chevalier, the divisions are cut on the outside of a ring which surrounds the



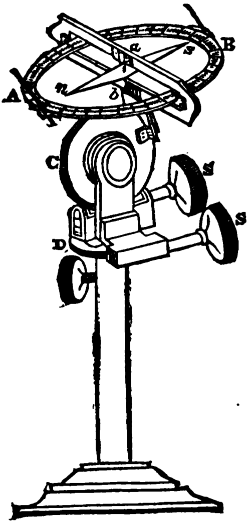
card, and the reflection is rendered unnecessary. These forms are not only better than the old azimuth compass, but are superior for the use of surveyor's to their ancient instrument. When the variation is to be determined with great accuracy, instruments called *Variation Transits* are employed. One of the most convenient of these is that constructed by Dollond, of London. This has a telescope instead of ordinary sights, and this is adapted to a vertical angle, by which astronomic observations for determining the time may be made simultaneously with those of azimuth. (See figure on page 271.)

The best form of an instrument for observing the dip is represented in the annexed figure.



The construction of the astatic needle is founded on the principle that a body which is moveable round an axis cannot receive any motion from a force which acts parallel to this axis.

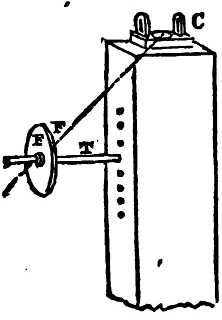
The astatic needle is represented in the annexed figure, where *n s* is a magnetic needle, moveable round the axis *a b*. If this axis is placed in the direction in which terrestrial magnetism acts, the needle will rest in any position. This effect is easily produced by two motions perpendicular to each other, one of which is obtained by the milled head S′, which, by an endless screw on its axis, works in the teeth of the wheel C, and the

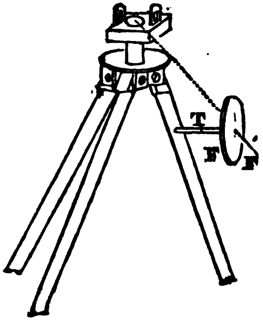


other by the milled head S' and the wheel D, the graduated circle, A B, showing the positions of the needle.

The quantity of iron which enters into the structure or forms a part of the equipment of ships, has a great influence upon the direction of the needles of their compasses. The deviation thus caused has amounted, in some cases, to 15° or 20°. In order to correct this source of error in the compass, an apparatus has been contrived by Barlow, which is delineated in the figures represented below.

The compass box, C, is placed on a wooden case, on one side of which are pierced a number of holes. Through either of these a copper rod, T, may be passed. This rod carries two iron plates, F F. The compass having been used on board of the ship, while it is veered completely around, the deviation can be measured by reference to a fixed mark on the shore. The compass is then removed to the





§ 312. The phenomena of magnetism have been connected together by two hypotheses of exactly the same nature as those which have been applied to the analogous phenomena of electricity. The first, or that of Æpinus, refers them to the agency of a peculiar fluid, having properties very similar to those of the electric fluid in the hypothesis of Franklin, but which act only upon ferruginous bodies and Nickel. The particles of this fluid repel one another with a force which decreases as the distance increases, and they are attracted by the particles of iron with a force varying according to the same law. This hypothesis farther requires the supposition, that the particles of iron repel one another according to the same law.

The second hypothesis is exactly similar to the electric hypothesis of Du Fay, and is founded on the supposition of two magnetic fluids residing in the particles of iron, and incapable of quitting them. One of these imparts the northern, and the other the southern polarity, and they have been denominated respectively the *boreal* and *austral* fluids. The particles of each attract those of the other, but repel those of the same kind. When in combination

land, and placed on the case, to which the rod T, and the plates F and F′ are adjusted. The case is then turned around, and the deviation produced by the attraction of the plates observed. It is obvious that the amount of this deviation may be changed by placing the rod T in different holes, and and by drawing out or pushing in the rod. This is done until the deviation produced by the plate is the same as that observed on board of ship. The compass is then returned to its position on shipboard, where it is mounted on a stand, as represented in the last figure on the preceding page, to which the plates F F′ are adapted in exactly the same relative position as that determined by the observation on shore. The deviation on shipboard will now be doubled. It is, therefore, only necessary to observe the compass when the plates are in the position presented, and when they have been removed to a distance. The difference in the direction of the needle in the two positions is the quantity of deviation produced by the magnetic action of the vessel.

with each other, these fluids are inactive; each becoming active only when separate. The decomposition of the neutral fluid is effected by the inductive influence of either the one or the other when acting independently. Both hypotheses differ from the corresponding electrical assumptions by the necessary condition that the imponderable fluid cannot travel from particle to particle, but that the magnetic elements or atomic portions of matter to which they are attached, are separated from each other by extremely small spaces, within which the displacements and motions of the magnetic fluids are restricted.

Either of these general views affords a sufficient basis for mathematical calculations which embrace all the leading facts of the science, but cannot for a moment be supposed to represent the real mechanism of the phenomena, especially since the inseparable connexion which has lately been proved to exist between the electrical and magnetical forces, into the nature of which it will now be our business to inquire.

ELECTRO-MAGNETISM.

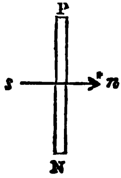
§ 313. We are indebted to Professor Œrsted for having laid the foundations of *electro-magnetic* science upon well-devised and convincing experiments. The apparent analogy between the phenomena of electrical and magnetical induction, as well as the uncertain effects of electrical discharges, both natural and artificial, upon the magnetic needle, to which we have already referred (§ 287), early induced philosophers to suspect an intimate connexion between their causes, and various attempts were made to establish such a relation. Nothing, however, satisfactory had been effected up to the time of the Danish philosopher's researches. The effects of electrical currents and discharges upon the needle had always been sought for at the points where the other effects had been produced, namely, at the poles or interruption of the circuit; but he found them in the uninterrupted current and the closed circuit.

§ 314. When a wire, connecting the generating and conducting plates of a voltaic battery, is laid in a heap of iron filings, they adhere all around it equally, and not more towards the extreme ends than at any other part, and present the appearance of a closely compacted layer, instead of that bristled, divergent arrangement which characterizes the polar attraction of the ordinary magnet. When the circuit is broken in any part, they immediately fall off under the force of gravity.

The general effect of the conducting wire upon the magnetic needle has already been described; the latter is not attracted by either of its poles, as by a magnet, but tends to place itself across the wire; the direction of its poles always having a constant relation to the direction of the voltaic current.(75)

§ 315. The conducting wire produces no effect upon needles of brass or other non-magnetic metal; nor of needles of glass or lac suspended in the same way as the magnetic needle; but its action is freely transmitted through glass, metals, wood, water, or resins; hence it is inferred that the active force is not that which we have distinguished as electrical, but agrees in character with the magnetical.

§ 316. Electro-magnetic effects do not depend upon the intensity of electricity, or the number of the battery series, but solely upon the quantity thrown into circulation, or the efficient size of the conducting surface.



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(75) If P N represent the conducting wire, the position of the needle, *s n*, will depend upon its being above or below the wire. If, when above the wire, the position of the marked end, *n*, be to the right, when placed below the wire the same end will be directed to the left.

Professor Œrsted early found that a plate of zinc, of 100 square inches, immersed into a corresponding copper vessel containing dilute acid, acted upon the needle at the distance of three feet, but that, when forty such combinations were placed in series, the effect was not increased.

§ 317. The magnetic force of the conducting wire is capable of acting by induction upon soft iron, and of communicating a permanent magnetic polar condition to bars of steel. If needles be attached to the wire in different directions by fine silver wire, some parallel, others transverse, above and below, they will all become magnetic when the current is transmitted. Those which are parallel to the wire will attract filings in the same way as the wire itself, but those in a transverse direction will exhibit each two poles. All the needles which are placed under the wire will have their poles in one direction, while those which are over it will have their poles in the contrary direction. On breaking the circuit, the needles that were on the wire in a transverse position will retain their magnetism, while those that were parallel to it will be found to lose their force at the same time as the wire itself. The opposite action of the opposite sides of the wire, which we have already found to be indicated by the magnetic needle, is manifest in these permanent effects.

§ 318. These magnetic actions are capable of a high degree of concentration by coiling the wire in such a way as to bring many portions of the same side to bear upon one point. Many hundred needles, fastened in a transverse direction upon the under part of the conducting wire, would instantly be magnetized to the same amount and in the same direction: but if the wire be twisted in the manner of a corkscrew, so as to form a hollow spiral, a needle placed within it will cross it many times by its several turns, and have the force concentrated upon it, which was previously diffused over the whole number of needles. Such a spiral conformation is denominated a *helix*. It will be obvious, upon a little reflection, that, accordingly as the circumvolutions of such a helix are directed from right to left, or from left to right, or in the manner of a right-handed or left-handed screw, the upper or the under side of the originally-horizontal wire will be turned inward, and the direction of the accumulated force will vary accordingly. To prevent direct communication between the coils of the wire in experimenting with such an arrangement, the conducting wire should be covered with silk; or it may be twisted round a glass tube; which substances, while they insulate the electric forces, are freely traversed by the magnetic. A steel needle, placed in the axis of such a cylinder, becomes instantly and permanently magnetic, and, as its two poles are oppositely acted upon by the single force of the one side of the wire which is directed upon it, it will place itself directly in the centre, where alone it can be in a state of equilibrium between the attraction and repulsion which impel it in contrary directions. When disturbed from this position by being pushed nearer to one end, the forces derived from the turns of the wire collectively act with more power upon that pole which is nearest to the middle point of the axis. They will, therefore, prevail over those that urge the more distant pole in the contrary direction, and the magnet will be brought back to its former position in the centre. So powerful is the action of a helix of this description, that, if a small steel bar be placed within it, and supported in a perpendicular position, the moment the connexion is made with the voltaic battery, it will be seen to start up, and place itself in the axis, remaining suspended in opposition to the force of gravity.(76) A heavy body, thus hanging in the air, without any visible support, realizes the situation of the iron coffin of the impostor Mohammed, which is fabled to be thus balanced, without any material connexion and support, between two loadstones.

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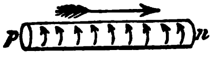
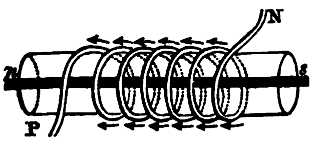
(76) Let *p n* represent a conducting wire, in which the elec

§ 319. It will now be understood why, in describing the magnetic effect produced by the discharge of the Leyden apparatus, this form of the helix was adopted; and in the result which has been described will be seen the confirmation of the opinion that the electricity of the common electrical machine, in the moment of its discharge, must be regarded as in the same current state as that of the voltaic battery. The intensity of the induced magnetism is found to be proportional to the quantity of electricity transmitted through a wire in a given time, whatever the source of that electricity may be, and the magnetizing effects are produced nearly instantaneously.

The concentration of magnetic action, from a wire conducting a current of electricity, may be carried still farther by piling the coils of the helix one upon another in the same direction; five, or six, or more layers in succession, may be thus compacted together, and each will add proportionately to the effect. No limits have been determined to this accumulation, provided the intensity of the current be increased in proportion to the increased



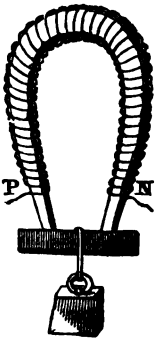
trical current is flowing in the direction of the large dart, and the small darts will then exhibit the direction of the magnetic force.



In figure 2, the same wire, P N, is shown coiled in a spiral form round a glass tube, and it is seen that the magnetism tends the same way in each convolution, and thus acts with concentrated energy upon the needle, n s, placed in the axis of the arrangement.

resistance of the wire by the impulse of a battery series. The effect of the outer coils are transmitted without any diminution from the action of those within.

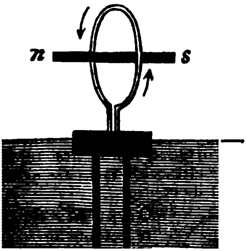
§ 320. Electro-magnetic induction also takes place temporarily in soft iron, and a very powerful magnet may be obtained by bending a thick cylinder of the best metal into the form of a horseshoe, and surrounding it with a coil of copper wire, covered with silk or other non-conducting material. When the current of a moderate-sized battery is transmitted through the wire, the iron becomes powerfully magnetic, and will support a very heavy weight by means of a keeper applied to its poles, precisely in the manner of a common horseshoe magnet. When the electric circuit is broken, all the attractive force ceases, and the weight falls to the ground. If, instead of breaking the connexion with the battery, the electric poles be changed so as to reverse the direction of the current, the poles of the magnet are changed with the utmost rapidity. The weight momentarily separates from them, but is instantly again attracted, and sustained with the same force as before. These effects are much increased by augmenting the number of coils upon the iron, without extending the length of the wire.(77) In an experiment made by Professor Henry, of Princeton, a horseshoe of iron was wound with twenty-six strands of copper bell-wire, covered with



(77) This figure represents the conducting wire, P N, of a voltaic circuit, covered with silk, to prevent metallic contact, wrapped spirally round a bar of soft iron, bent into the form of a horseshoe. While the current is passing, the iron is converted by induction from the wire into a magnet exactly resembling the permanent magnet represented in figure 70, p. 261.

tton thread, thirty-one feet long: about eighteen ches of the ends were left projecting, so that venty-eight feet only of each actually surrounded e iron. The whole length of the coil was, there- re, 728 feet. Each strand was wound on a little ss than an inch; in the middle of the horseshoe it rmed three thicknesses of wire, and on the ends it as wound so as to form six thicknesses. With a ttery of five feet square, this electro-magnet sus- ended 2063 pounds, or nearly a ton weight.

§ 321. If the conducting wire of the battery, in- ead of being coiled into a hollow helix, be bent to a flat spiral, and be attached to one side of a rd, through which the central wire passes, and scend in a straight line on the other side, the op- osite surfaces will present opposite polarities, and e arrangement will imitate the effects of a mag- t whose poles might be supposed to be situated in e centre of each disc. A wire of this form will llect a prodigious quantity of iron filings, which, the rings are not continued quite to the centre, ill arrange themselves in lines passing through the en ring parallel to the axis, and then closing up radii round the centre.(78)

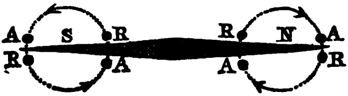


(78) This figure represents the conducting wire connecting the zinc and copper plates z and c, which are made to float by a cork in a basin of dilute acid, wound into a flat spiral. A current will then circulate in the direction of the arrows, and each side of the circle will have the opposite properties f two powerful magnetic poles. ne end of a magnet (n s) pre- ented horizontally to its axis, will cause the ring to move towards it till it reaches its centre, where it will rest in a state of equilibrium. If the magnet be withdrawn, and its poles rever-

It will be understood that, in all these cas direction of the poles of the arrangements de first, upon the direction of the current with ence to the axis of the helix, and, secondly the direction of the circumvolutions which co it; or, in other words, upon the position of th ducting wire with regard to the generating an ducting metals of the voltaic combination, an the part, upper or lower, as the case may be, action is concentrated by the spiral folds.

§ 322. We must now return to a more par examination of the action of the single wir the magnetic needle, which is not of the sim ture which at first appears, but which was a by Dr. Faraday with his usual ability. If it be in a perpendicular position, and made to ap towards one pole of the needle, the pole will simply attracted or repelled, but will make an to pass off on one side, in a direction dep upon the attractive or repulsive power of the but if the wire be continually made to approa centre of motion by either the one or other s the needle, the tendency to move in the forn rection will first diminish, then become null, a timately the motion will be reversed, and the will powerfully endeavour to pass in the oppos rection. The opposite extremity of the needl present similar phenomena in the opposite tions.(79) Dr. Faraday drew the conclusio

sed, and (the ring being held in its first position) it be half way through the ring, the latter, when loosed, will, placed exactly in the centre, move towards the pole w nearest to it, and, when clear of the magnet, will be firs led, and then, turning round, will be attracted, and pas over the pole, and rest in equilibrio at its centre.



(79) This represents h tal sections conducting different p

the direction of the forces was *tangential* to the circumference of the wire; that the pole of the needle is drawn by one force, not in the direction of a radius to its centre, but in that of a line touching its circumference; and that it is repelled by the other force in the opposite direction. In this manner, the northern force acted all round the wire in one direction, and the southern in the opposite. Each pole of the needle, in short, appeared to have a tendency to revolve round the wire in a direction opposite to the other, and, consequently, the wire round the poles. Each pole has the power of acting upon the wire by itself, and not as connected with the opposite pole, and the apparent attractions and repulsions are merely exhibitions of the revolving motions in different parts of their circles.

§ 323. The needle, in its usual mode of suspension, in which the two poles, which are oppositely impelled, are both subjected to the action of the same part of the wire at the same time, cannot, of course, exhibit these rotatory motions; it rests in a state of equilibrium between the two forces across the wire; but, by ingeniously limiting the action of the electricity to one pole, Dr. Faraday succeeded in producing the actual rotation of the pole about the wire, and of the wire about the pole. He immersed a small magnet perpendicularly in mercury, confining its lower end to the bottom of the vessel in which it was contained; it thus floated, almost vertically, with one pole above the surface: a wire was then fixed perpendicularly, so as just to touch the mercury in the neighbourhood of the pole, and, when a current of electricity was transmitted through the wire from a voltaic circuit, the pole im-

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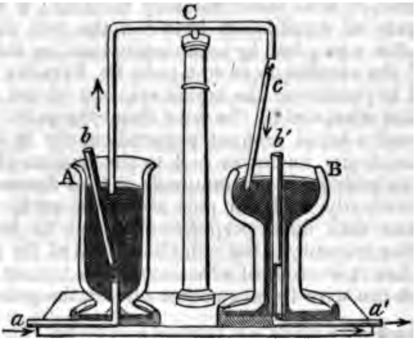
with regard to the needle, S N, balanced in its centre. They are marked A or R, according as they appear to attract or repel the adjacent poles S and N; and the arrow heads indicate the direction of the circular motions which would result if the poles could be insulated.

mediately began to rotate about the wire. The direction of the rotation depended upon the mutual relation of the pole and current. When the current from the zinc to the copper descended the wire, the marked pole rotated from left to right; the unmarked pole from right to left; and, when the current was reversed, the rotation was changed. (80) When once

(80) The following figure represents an apparatus by which the rotation of the pole of a magnet round the conducting wire, and the corresponding rotation of the wire round the fixed pole, may be exhibited. A is a glass vessel, in the bottom of which a hole is drilled, by which a metallic communication is made with the mercury contained in it, with the wire of a voltaic circuit, *a*; a small cylindrical magnet, *b*, is attached by a thread, fastened to one of its ends, to the bottom of the cup, so that it may float almost upright in the mercury. The voltaic circuit is completed by means of a wire proceeding from the brass stem *c*, dipping just below the mercury in the cup. When a current is thus established through the wires and the mercury in the cup, in the direction marked by the arrows, the pole *b*, which alone will be acted upon, will revolve about the fixed conductor.



B is a similar glass vessel, filled also with mercury, in which the magnet *b′* is fixed to the bottom, one of its poles projecting a little above the surface of the mercury. The wire *c*, which completes the voltaic circuit, is suspended by a loop, so as free-the principle had been illustrated, the suspension of both magnet and needle were varied by different experimenters in many different ways; and even the thermo-electric currents excited in two parallelograms of silver and platinum wires, fixed across each other, and heated, at the points of junction of the two metals, by a spirit-lamp, were made to rotate under the influence of a magnetic pole.

§ 324. When the electrical current is made to descend through the upper half of the magnet itself, delicately resting upon a point, so as to act exclusively on the pole which is situated in that half, and is then diverted from the lower half, which may be effected by copper wires projecting from the centre and one end, and dipping into circular grooves filled with mercury, the magnet will rotate with considerable velocity upon its axis.

§ 325. The influence of the pole of a magnet upon electrical currents may be exemplified by liquid as well as by solid conductors. By immersing the two electrodes of a voltaic battery into mercury contained in a shallow basin, a magnet, held either above or below the line of communication, will cause the mercury to revolve round the points from which the currents diverge. Even the flame which is produced by the continuous discharge of a powerful voltaic battery between two charcoal points, is obedient to the same laws; for Sir Humphrey Davy found that the arched stream of light produced by a battery of 2000 plates, was thrown into a rapid rotatory motion by the action of the pole of a magnet placed near it. A very pleasing way of showing this effect is to make a powerful horseshoe magnet part of the conducting wire of a constant battery of a moderate

ly to move round the pole. When the current is established in the direction of the arrows, the wire commences its revolution. But these rotations may at once be produced by the same current by connecting the wire *a* with the zincode, and *a'* with the platinode, of a voltaic battery.

number of cells; the flame, which may then be drawn from one of its poles, will rotate in one direction, and that from the other in the opposite.

§ 326. The current of electricity, which passes through the cells of the voltaic battery itself, exhibits the same electro-magnetic properties as those in the conducting wire, and a needle is affected by it in the same way. If a double cylinder of copper, of about two and a half inches diameter, and of the same height, closed at the bottom, so as to be capable of holding dilute acid, be supported by an arch of copper upon a point resting upon one end of a perpendicular magnet, and if a cylinder of zinc, lightly constructed, and dipping into the cell, be supported by another point upon the top of the former, both cylinders will freely turn upon their points. The two together will constitute a single cell of a voltaic battery, and, when filled with acid, an electric current will pass from the zinc to the acid, and will ascend from the copper through the pivot back again to the zinc. The zinc, therefore, is in the condition of a conductor, conveying a stream of electricity downward, and will, consequently, revolve under the influence of the magnetic pole which it surrounds. The copper cylinder, on the contrary, is in the situation of a conductor conveying a current upward, and will revolve in the contrary direction.

§ 327. Such a circumferential action and tangential direction of a force was wholly unknown to the time of Dr. Faraday's discovery. All other know forces emanating from a point, and exerted upon another point, act in the direction of a line joining these two points; and such is the case with the electric and magnetic actions considered as unconnected.

§ 328. Another general fact was ascertained by M. Ampère soon after the discovery of Œrsted. When two conducting wires are suspended in such a way as to be capable of moving either towards or from each other at the time that electric currents are passing through them, they mutually attract or repel one another, according as the currents are moving in the same or in opposite directions. It does not matter whether the currents be derived from the same battery or from two; when they flow in the same direction, they will manifest a mutual attraction; when in opposite directions, a mutual repulsion. This action is variously modified when the relative inclinations and positions of the currents are varied.(81)

When a slender steel wire is coiled into a helix, and placed in the voltaic circuit, it will instantly shorten itself whenever a current is sent through it, owing to this mutual action of the different rings of the coil through which the current passes in the same direction, and it will recover its former dimensions, from its elasticity, the moment the current ceases.

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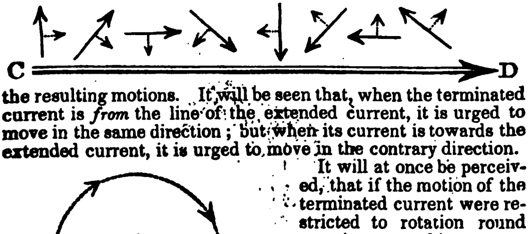
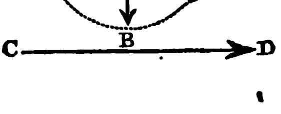
(81) Let C D be an extended current passing from C to D, and the upper lines represent various positions of terminated currents, of which the directions are marked by the terminal arrows. The dotted arrows will then point out the directions of the resulting motions. It will be seen that, when the terminated current is *from* the line of the extended current, it is urged to move in the same direction; but when its current is towards the extended current, it is urged to move in the contrary direction.



It will at once be perceived, that if the motion of the terminated current were restricted to rotation round an axis at one of its extremities, as shown in the annexed figure, the action of the current, C D, would carry the terminated current, A B, round the whole circumference of the circle.



§ 329. M. Ampère assumes the mutual attractions and repulsions of electric currents as the fundamental fact to which, by the help of a particular hypothesis respecting the constitution of magnets, all the other facts, not only of electro-magnetism, but of magnetism also, are reducible. He supposes that all bodies possessing magnetic properties, including the earth itself, derive those properties from currents of electricity continually circulating among the particles of which they are composed, and having, with relation to the axes of these bodies, a uniform direction of revolution, in planes perpendicular to those axes. We have already seen (§ 319), that the action of conducting wires, rolled into the form of a flat spiral, produces on one side the effects of a marked pole, and on the other of an unmarked pole of a magnet. The actions of a helix at its two extremities, and at some distance beyond them, is similar; and if the two ends of the wire which has formed the helix be bent back so as to return in a straight course along the axis till they arrive at the middle point, where they are again bent at right angles, so as to pass out between the coils, it may be freely suspended in various ways, and will completely imitate a magnetic cylinder. Such an *electro-dynamic cylinder*, as M. Ampère has named it, may be substituted in almost every form of experiment for a magnet, whose properties it will possess only so long as a current of voltaic electricity is transmitted through it.(82)

§ 330. We formerly (§ 312) referred to the hypothesis of *magnetic elements*, which was adopted to account for the phenomena attending the fracture of a magnet, and which considered each particle of magnetized iron as a separate magnet; in like man-

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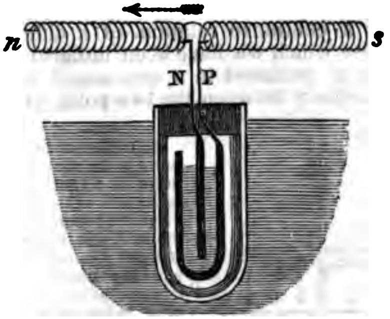
(82) Such an electro-dynamic cylinder is represented opposite,
its ends, after returning through the coil, *n s*, are attached to the
wires, N P, of a small voltaic circuit, consisting of a plate of

M. Ampère's hypothesis regards the electric cur-
ı, to which a magnet owes its properties, as cir-
;ing round each constituent particle, all of which,
ing in the same direction, will produce a com-
l effect which is equivalent to that of a circular
ent flowing uniformly round the circumference.
e regard a needle with its marked end pointing
ıe north, then the voltaic currents would ascend
ıe western side, pass from west to east in the
ır surface, and descend on the eastern side:
would circulate, that is, in a direction contrary
ıat of the currents which are supposed to pro-
ı the magnetism of the earth.

331. All the principal effects of terrestrial mag-
ım may be imitated by distributing a wire round
surface of an artificial globe, in a spiral direc-
, from the equator to the poles, the two extrem-
being turned inward, and brought out at the two
ı, by which the connexion may be made with

surrounded by a plate of copper, and floating in a basin of
ı acid, in which it is free to move. Such a spiral will



taneously place itself in the magnetic meridian under the
ence of the earth's magnetism, and will be obedient to an-
r magnet brought to either of its poles.

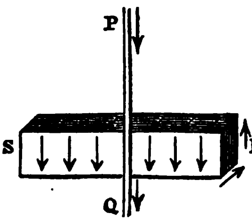
the battery. A magnetic needle, prop
ed in different situations near such a g
range itself in positions perfectly analo
actually assumed by the dipping need
sponding regions of the earth.

The origin of the currents which mu
père's theory, circulate in the globe
west, in planes parallel to the magn
may possibly be found in the action
rays on successive parts of the torrid
cing thermo-electric currents in that d

§ 332. The tendency which a magn
ducting wire have to place themselves
gles to one another, follows from the sa
sis, and may be ascribed to the ten
transverse currents in the magnet i
the conductor to establish a paralleli
them.(83)

The phenomena of revolving motio
by the tangential force are also easi
upon the same principles; but we must
selves with this brief indication of a t
has conferred immortal honour upon it

§ 333. A continued rotation, of a d
from those which we have been hithe
ing, may be produced in a spur-wheel
perpendicularly between the two poles



(83) Since th
rents in the ma
move in plane
to the axis of th
magnetic action
the axis, and t
straight conduc
into the trans
represented in t
ure. When in
sition, as the ad
move in the s
they will attrac

shoe magnet, when a voltaic current is transmitted across its diameter by means of some mercury in a groove, into which the wheel is made to dip to allow of freedom of motion. If a mere wire, conducting a current, be suspended in the same situation, it will be attracted or repelled, according to the direction of the current; the opposite poles, acting upon opposite sides of the wire, concurring to give it the same direction. In either case it will be thrown out of the mercury, and the circuit being thereby broken, the effect will cease till the wire falls back by its own weight and restores the connexion. The current will then be re-established, and the same influence again exerted. If the wire terminate in a spur-wheel, dipping by its radii into the mercury, as one radius is thrown out of the mercury, another will enter it, and the wheel will revolve with great rapidity. It is not even necessary to divide the wheel into rays in order to produce the effect; for a circular metallic disc will revolve equally well when it is traversed by an electrical current passing into mercury between the poles of the magnet.

§ 334. The voltaic current may be influenced by the earth's magnetism precisely in the same way as by a permanent magnet, or an electro-dynamic cylinder; and wires delicately suspended have been made to exhibit all the phenomena of attraction, repulsion, direction, and rotation, by its action, although but feeble.

MAGNETO-ELECTRICITY.

§ 335. The phenomena of electro-magnetism are produced by electricity in motion; accumulated electricity, when not in motion, exerts no magnetic effects. Dr. Faraday early felt convinced that, "as every electric current is accompanied by a corresponding intensity of magnetic action at right angles to the current, good conductors of electricity, when placed within the sphere of this action, should have a current induced through them, or some sensible effect produced equivalent in force to such a current." These considerations, with their consequence, the hope of obtaining electricity from ordinary magnetism, stimulated him to investigate the subject experimentally, and he was rewarded by an affirmative answer to the question proposed. He thus became, like Œrsted, the founder of an entirely new branch of natural philosophy.

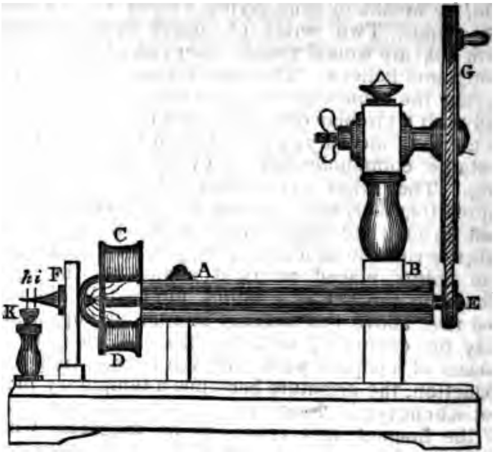
§ 336. If a wire connecting the two ends of a delicate galvanometer be placed parallel and close to the wire connecting the poles of a voltaic battery, no effect will be produced upon the needle, however powerful the current may be. If the points opposed in the two wires be multiplied by coiling the one, as a helix, within the convolutions of the other coiled in the same way, both being covered with silk to prevent metallic contact, still no effect will be discernible so long as the current is uninterrupted. When, however, the current of the battery is stopped by breaking the circuit, the needle is momentarily deflected, as by a wave of electricity passing in the same direction as that of the main current. Upon allowing the needle to come to a state of rest, and then renewing the contact, a similar impulse will be given to it in the contrary direction. While the current continues, the needle returns to its state of rest, again to be deflected in the first direction by stopping the current. Motion may be accumulated to a considerable amount in the needle, by making and breaking the contacts with the battery in correspondence with its swing.

§ 337. The same effects are produced when, the current being uninterrupted, the conducting wire is made suddenly to approach or recede from the wire of the galvanometer. As the wires approximate, there will be a momentary current induced in the direction contrary to the inducing current; and as the wires recede, an induced current in the same direction as the inducing current.

§ 338. After Dr. Faraday's discovery, many ingenious contrivances were made for exalting the effects and facilitating experiments. The most complete arrangement now in use was the original combination of Mr. Saxton.

A very powerful horseshoe magnet, formed of numerous steel plates closely applied together, or an electro-magnet of soft iron of the same form, is placed in a horizontal position. An armature of the purest soft iron has each of its ends bent at a right angle, and is mounted in such a way that the surfaces of those ends are directly opposed, and close to the poles of the magnet; in this position it may be made to rotate rapidly in a vertical direction, by means of multiplying wheels and an endless band. Two series of copper wires, covered with silk, are wound round either end of this bar, as compound helices. The extremities of these wires having the same direction, are connected together, and with a circular disc rotating with the armature in a cup of mercury, with which it is, therefore, in metallic communication in every position of the disc. The other extremities of the wires are united together, and, passing without metallic contact through the spindle upon which the apparatus turns, terminate in a slip of copper, with two opposite points placed at right angles to the axis. These, in the act of rotation, alternately dip into and rise above the mercury in another cup, which may be connected with the first at pleasure by means of a copper wire. By the laws of magnetic induction, the armature becomes a temporary magnet whenever its bent ends are opposite the poles of the magnet, and ceases to be magnetic when they are at right angles to them. The momentary generation and destruction of the magnetic force, which will be oppositely directed in the bar as its opposite ends become opposed to the same poles i the act of rotation, must, by the laws of magneto-electric induction, induce corresponding opposit electric currents in the copper wire if the circuit b complete, by the immersion of the points at the moment of their passage. The points are so arrange that, standing nearly at right angles to the revolving bar, they just rise from the mercury as its end become opposed to the poles of the magnet, and th circuit being thus suddenly broken at the momen of the electric wave, the current passes in the form of a brilliant spark.(84)

(84) This figure represents a section of Mr. Saxton's magneto-electrical machine. A B is the horseshoe magnet. C D th armature of soft iron, standing in a transverse direction to th poles of the magnet. E F is the spindle upon which it revolve by means of the multiplying wheels E G. *h* and *i* are the metallic wheels and points by which connexion is made and broken between the mercury cup, K, and the ends of the coils of wir round the armature, C D.



§ 339. By means of this magneto-electrical machine, all the well-known effects of voltaic currents may be very commodiously produced. When the communication is made between the spindle and the revolving disc, by means of a fine platinum wire instead of the dipping points, the wire may be maintained at a red heat; although the effect being produced by alternating currents in opposite directions, a kind of pulsation, or intermission of the light, may be discerned. Upon making the communication between the two mercury cups by means of copper cylinders grasped in the hands, a continued painful contraction of the muscles of the arms takes place, which destroys voluntary motion, and, under certain circumstances, is perfectly intolerable. If the currents be transmitted into liquid electrolytes by means of platinum electrodes, they are readily decomposed.

§ 340. However large the quantity of electricity may be which is thrown into circulation by a single voltaic circuit, its intensity is very low, and it is wholly incapable of effecting its passage by *disruptive discharge.* In consequence of this, when the conducting wire is very short, no spark is visible upon making or breaking contact between the generating and conducting surfaces; or, at most, a very minute one upon the latter occasion. Nevertheless, when the wire is long, a very bright spark is produced upon breaking contract. This spark is greatly increased when the same long wire is coiled up into a helix; and still more when it is wound round an iron core, so as to constitute an electro-magnet. Under these last circumstances, if the ends of the wire near the battery be grasped by a person with moistened hands, he will receive a considerable shock at the moment of breaking the contact at a point between the place at which it is held and the battery, and the spark will be diminished. If a decomposing apparatus be interposed between the same extremities of the wire, the direct current will pass through the latter so long as the contact with the battery plates is maintained; but, on breaking contact, iodide of potassium will be decomposed in the former, and the situation of the evolved iodine will prove that the decomposition has been effected by a current in an opposite direction to that of the battery current. In this last experiment a bright spark occurs at the place of disjunction, indicating that only a small part of the extra current passes the decomposing apparatus because of its small conducting power. The most instructive set of results are, however, obtained when a galvanometer is introduced between the extremities of the conducting wire. When contact is then made, a portion of the primary current which passes through the principal wire is diverted through the galvanometric wire, and the needle is deflected. If, while in this situation, it be forced back by pins, applied upon opposite sides of its two extremities, to its natural position when uninfluenced by a current, and the battery contact be then broken, it will be strongly deflected in the opposite direction; thus showing that the extra current followed a course in the cross-wires contrary to the one produced by the direct action of the electromotor.

§ 341. It is clear, then, that, at the moment of its return to its natural state, a reflex wave of electricity is generated in the conducting wire, which is analogous to that which it is capable of inducing at the same moment in a parallel independent wire. It is generated, also, by the same lateral or magnetic force, and it is increased, like the latter, by the reaction of the temporary magnetism of soft iron in the moment of its cessation, and by the juxtaposition of the coils of a helix.

In fact, if a second and independent wire be placed by the side of the primary conducting wire, as by coiling the two together in one helix, taking care that they may be well insulated, so long as the circuit of the second wire is not complete, the primary wire will give a good spark; but, upon completing the secondary circuit by bringing its ends into metallic contact, the whole of the lateral force will be expended upon it, and little or no spark will appear when the primary circuit is broken. Then, again, if the ends of the second wire should happen to be disconnected at the moment when the battery contact is broken, a spark will there appear instead of occurring at the disjoined extremity of the principal wire. Even the weak current of the thermo-electric circuit (§ 284) may be made to yield a spark from this secondary action by the assistance of a helix.

§ 342. In the wire of the helix of the magneto-electric machine, these principles of action have an important influence. From the construction of the apparatus, the current is permitted to move in a complete metallic circuit of great length during the first instance of its formation: it gradually rises in strength, and is then suddenly stopped by the breaking of the metallic circuit; and thus great intensity is given by induction to the reverse current which at that moment passes. Different effects are produced by varying the length and diameter of the wire upon the armature. A great length (1500 yards) of fine insulated copper wire will decompose water with the greatest advantage, and give the severest shocks; but a less length (40 yards) of thicker wire will give the largest sparks, and ignite the largest quantity of platinum wire.

§ 343. By a primary coil of thick wire of 120 feet in length, the connexion of which with a voltaic circuit may be rapidly made and broken by a spring pressing upon a toothed wheel and an inducteous coil of finer wire 120 yards long, the ends of which may be grasped by the hands, an electro-dynamic machine may be constructed, the effects of which are utterly intolerable. The continuous shock of this instrument is sufficient to destroy life in a cat, or other animal of the same size, if directed through the head.

§ 344. In the voltaic circuit, the self-induction of the conducting wire generates a current which pervades the cells of the battery itself as well as its own substance; for if a long wire or coil be connected with a series of cells, not only will the large spark be formed when the circuit is broken at the extremity of that wire, but at any of the short wires of the other cells. The effect upon the electrolyte, from this reaction, has not yet been examined.

345. If we now cast a retrospective glance upon the collective phenomena which have come before us, how wonderful appears the nature of that mysterious force, which we can at pleasure call into action by the mutual influence of masses of metal upon each other exerted at a distance, and without diminution of substance or power; or from the union of a few grains of zinc and oxygen, accompanied by the simultaneous disunion of equivalent proportions of oxygen and hydrogen! A force which, at the same moment and in one circuit, will radiate the only light which is capable of rivalling the intensity of the solar beam; disengage a heat which will fuse the most refractory metal; control and paralyze the muscular energies of the most powerful animals; suspend the force of gravity, and give mechanical motion to masses of matter; and, acting upon the ultimate molecules of matter, will decompose the most intimate combinations of affinity at one point, and recompose them at another!!

Mere differences of temperature in some substances, and the mutual friction of others, will also call this marvellous agent forth; and, to complete our admiration, we have now to contemplate it as the product of animal life, and placed as an offensive weapon under the control of animal will.

ANIMAL ELECTRICITY.

§ 346. There is a flat fish, a species of ray, which frequents the shores of the Mediterranean, the Atlantic coast of France, and is sometimes taken on the southwest coast of England, which was known to the ancients as capable of communicating a benumbing sensation to those who handled it, and to which they therefore gave the name of torpedo. Several of the early physicians, both Roman and Arabian, ascribed to it an influence in subduing obstinate headaches, and the gout itself.

§ 347. The vague notions which were entertained of the nature of this animal force, even in later times, cannot be better exemplified than by an extract from a paper on the subject, published in the *Philosophical Transactions* for 1678, by Stephano Lorenzini. He observes: "The chief wonder of this animal, and that which gives it its name, is the benumbing faculty which is seated in the two semicircular or falcated muscles on each side of the thorax, which consists of fibres, irregular, but as large as a goose-quill, and made up of bladders filled with a kind of water; one end of these fibres being fixed to the skin of the belly, and the other to that of the back, on which may be plainly seen the vestigea of the fibres' ends. Now, when the fish contracts those fibres, there issue out corpuscules fitted to the pores of a man's skin, so as to enter upon immediate contact, but not otherwise, and disturb the posture of the parts, and to cause pain, as when one's elbow is hit or knocked; and this comes most by the fingers' ends, because these are ends of tendons. And this pain is more or less as the contraction of the fibres have immitted more or less."

§ 348. As a contrast to these untenable, hypothetical assumptions, we may refer to a paper on the same property of the torpedo, by Mr. Walsh, in the *Philosophical Transactions* of the year 1773. He set out, also, with a hypothesis which, at the time, was sufficiently bold, that the effect was *electrical;* but, in the true spirit of the inductive philosophy, he immediately proceeded to test the sufficiency of the supposition by well-devised experiments. He found that the shock of the torpedo could be transmitted through conductors of electricity, as metals and water; and that it was interrupted by non-conductors, as glass and sealing-wax. He discovered that the back and breast of the animal were in different states of electricity; and that, to receive the shock, it was necessary that there should be a conducting communication between the upper and lower surfaces. The shock, when in air, appeared to be about four times as strong as when in water. His results have been confirmed and extended by recent experimenters, and particularly by Dr. Davy, who succeeded in effecting chymical decomposition, the magnetization of steel, and the deviation of the magnetic needle, by the electrical current of the torpedo. He also ascertained that the electrical organ upon the under surface of the animal corresponded to the zinc extremity of the voltaic circuit, and its upper surface to the copper extremity.(85)

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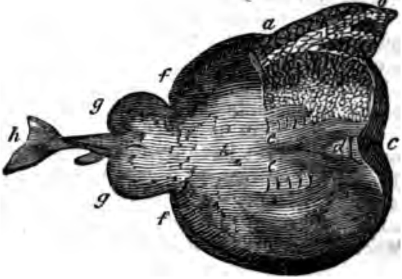
(85) The annexed figure presents a view of the under surface of the torpedo. *a* is the right electric organ, exposed by



§ 349. This power of generating and directing an electrical current at pleasure is also possessed by a fresh-water fish, *gymnotus electricus*, which at first view appears very much to resemble an eel, and which, consequently, has been named the *electrical eel;* a fine specimen of which, forty inches in length, is now being exhibited in the Adelaide Gallery. It is common in all the small rivers which flow into the Orinoco in Guiana, and also in Surinam.

§ 350. Dr. Faraday has lately experimented with this animal, and communicated the results to the Royal Society. He employed two collectors formed of copper plate, bent into a saddle shape, which passed over the fish, and enclosed a certain extent of the sides and back, and thick copper wires were brazed to them to convey the electric force to the experimental apparatus. They were covered with sheet caoutchouc, the edges of which projected at the bottom and ends, and the parts of the wires liable to be in the water were also covered with the same substance. By these means, the part of the animal within the caoutchouc was insulated from the surrounding water. The greatest effects were produced when the collectors were applied to the anterior and posterior parts of the gymnotus.

Dr. Faraday concludes, that a single medium discharge of the fish is at least equal to the electricity of a Leyden battery, containing 3500 square inches

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dissecting off the skin, which consists of white pliant columns, in a close, and, for the most part, hexagonal arrangement, giving a general appearance of a honeycomb in miniature. These columns have sometimes been denominated cylinders; but, having no interstices, they are all regular, and chiefly six-cornered. *b*, the skin which covered the organ, showing on its inner side a hexagonal network. *c*, the nostrils in the form of a crescent. *d*, the mouth in a crescent contrary to that of the nostrils, furnished with several rows of very small teeth. *e*, the branchial apertures, five on each side. *f f*, the outward margin of the greater lateral fin. *g g*, the two smaller lateral fins. *h*, the fin of the tail.

of glass coated on both sides, charged to its highest degree; and, notwithstanding the greatness of this force, the animal can give a double and triple shock with scarcely a sensible interval of time.

Using the saddle collectors, the needle of a galvanometer, not particularly delicate, was affected to the amount of 40°, and the current was always found to be from the anterior parts of the animal through the galvanometer wire to the posterior parts. An annealed steel needle, placed in a little helix, was rendered magnetic, and polar decomposition of a solution of iodide of potassium was easily obtained. A secondary spark was obtained by means of a good magneto-electric coil, and afterward a direct spark between the surfaces of two gold leaves.(86)

§ 351. It was evident from the experiments, that all the water and all the conducting matter around

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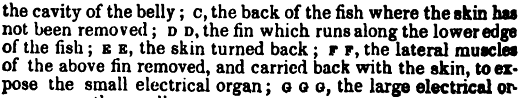
(86) This figure exhibits the whole of the two electrical organs on each side of the gymnotus, the skin being removed as far as these organs extend. They consist of two parts; viz., flat partitions or septa, and cross divisions between them. The outer edge of these septa appear externally in parallel lines, nearly in the direction of the longitudinal axis of the body. These septa are thin membranes, placed nearly parallel to one another. Their breadth is nearly the semi-diameter of the body of the animal. They are of different lengths, some being as long as the whole organ. A, the lower surface of the head of the animal; B, the cavity of the belly; C, the back of the fish where the skin has not been removed; D D, the fin which runs along the lower edge of the fish; E E, the skin turned back; F F, the lateral muscles of the above fin removed, and carried back with the skin, to expose the small electrical organ; G G G, the large electrical organ; H H, the small organ.



the fish, through which a discharge circuit can in any way be completed, is filled at the moment with circulating electric power; and a number of persons all dipping their hands at the same time into the tub, the diameter of which was 46 inches, received a shock of greater or less intensity, accordingly as they were more or less favourably situated with regard to the direction of the current.

§ 352. The gymnotus can stun and kill fish which are in various positions with respect to its own body. On one day, when Dr. Faraday particularly observed it, a live fish was dropped into the tub, and the gymnotus instantly turned round in such a manner as to form a coil enclosing the fish, the latter representing a diameter across it. A shock passed, and, in an instant, the fish was struck motionless, as if by lightning, in the midst of the waters, its side floating to the light. The gymnotus made a turn or two to look for its prey, which, having found, he swallowed, and then went searching about for more.

§ 353. To obtain an adequate idea of the power with which this extraordinary fish is armed, we must have recourse to the accounts of its action in its native streams; and the Baron de Humboldt has furnished us with the following graphic description of the Indian mode of fishing for gymnoti, by means of horses:

"The extraordinary noise caused by the horses' hoofs makes the fish issue from the mud, and excites them to combat. These yellowish and livid eels, resembling large aquatic serpents, swim on the surface of the water, and crowd under the bellies of the horses and mules. A contest between animals of so different an organization furnishes a very striking spectacle. The Indians, provided with harpoons and long slender reeds, surround the pool closely; and some climb upon the trees, the branches of which extend horizontally over the surface of the water. By their wild cries and the length of their reeds, they prevent the horses from running away and reaching the bank of the pool. The eels, stunned by the noise, defend themselves by the repeated discharge of their electric batteries. During a long time they seem to prove victorious. Several horses sink beneath the violence of the invisible strokes, which they receive from all sides in organs the most essential to life; and, stunned by the force and frequency of their shocks, disappear under the water. Others, panting, with mane erect and haggard eyes, expressing anguish, raise themselves, and endeavour to flee from the storm by which they are overtaken. They are driven back by the Indians into the middle of the water; but a small number succeed in eluding the active vigilance of the fishermen. These regain the shore, stumbling at every step, and stretch themselves on the sand exhausted with fatigue, and their limbs benumbed by the electric shocks of the gymnoti. By degrees, the impetuosity of this unequal combat diminished, and the wearied gymnoti dispersed. They require a long rest and abundant nourishment to repair what they have lost of galvanic force. The mules and horses appear less frightened; their manes are no longer bristled, and their eyes express less dread. The gymnoti approach timidly the edge of the marsh, where they are taken by means of small harpoons fastened to long cords. When the cords are very dry, the Indians feel no shock in raising the fish into the air."*

§ 354. In the anatomical construction of these animals, as displayed in the dissections of Mr. John Hunter, the most striking thing is the large proportion which the electrical organs bear to the rest of the bodies of the animals. In both species we recognise a structure which is contrived for large extension of surface in a small space, which reminds us of the similar construction of our voltaic arrangements. These are so abundantly supplied with nerves as to have led Mr. Hunter to remark, with regard to torpedoes, that "the magnitude and the number of the nerves bestowed on their organs, in proportion to their size, must, on reflection, appear as extraordinary as the phenomena which they afford;" and in speaking of the gymnotus, he says, "in this fish, as well as in the torpedo, the nerves which supply the organ are much larger than those which are bestowed on any other part for the purposes of sensation and action."

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* Personal Narrative, chap. xvii.

The electric organs of the torpedo and gymnotus cannot be considered as connected with those which are of direct importance to the life of the animal, but to belong rather to the common teguments; and it has been found that such torpedoes as have been deprived of the use of their peculiar organs, have continued the functions of life quite as well as those in which they were allowed to remain.

The nervous energy of the animals evidently becomes exhausted during the production of electricity, and there is an apparent production of electricity equivalent to the quantity of nervous force consumed.

§ 355. Living, as these animals do, in the midst of so good a conductor as water, our first thoughts are thoughts of surprise, that they can sensibly electrify anything; but a little consideration makes the perfect design of the whole arrangement obvious. It is by the conducting power of the water alone that the force can be communicated to the animal to be struck, and we may contrast this state of things with what would result if the body of the fish or its victim were surrounded with air.

The fate of a gymnotus which had been caught and confined for the purpose of transmission to this country, will illustrate the point. This animal, notwithstanding its wonderful powers, was doomed to perish ignobly under the attacks of a water rat. Much surprise was excited by this catastrophe; but all wonder ceases when we consider the perfect manner in which the body of the rat is insulated. When he dives beneath the water, not a particle of the liquid adheres to him; and his non-conducting fur, and the air which it contains, clothes him with armour which is perfectly proof against the bolts of his formidable antagonist.

§ 356. Never was there a more tempting field of research, or a higher reward offered for its successful cultivation, than that which is presented by *animal electricity*. In these electric fish we behold nervous power converted into electric force; it cannot be doubted that the converse of this is possible. We are, however, only upon the threshold of this inquiry of surpassing interest. It belongs, indeed, exclusively to the physiologist to connect these two branches of physical philosophy; but he who would take up the investigation with any hopes of success, must not only be well skilled in comparative anatomy and dissections, and conversant with the vital functions of animals, but must be master of all that is known of that extraordinary agent, the laws of which we have been endeavouring to expound under the names of *current affinity and electricity*, and must follow, with zeal and industry, the rapid progress which science is daily making in their development.

§ 357. The phenomena of the electric fish have lost none of their interest since the days when Mr. Walsh first communicated his experiments upon the torpedo to Dr. Franklin, and we cannot better take leave of the subject, at present, than by recalling the words with which he closed his letter upon the subject to that eminent philosopher.

"I rejoice in addressing these communications to you. He who predicted and showed that electricity wings the formidable bolt of the atmosphere, will hear with attention that, in the deep, it speeds a humbler bolt, silent and invisible. He who analyzed the electrified vial, will hear with pleasure that its laws prevail in animate vials. He who, by reason, became an electrician, will hear with reverence of an instinctive electrician, gifted in his birth with a wonderful apparatus, and with skill to use it."*

§ 358. We have heretofore (§ 189) seen heat associated with light, and both connected with, and developed by, electricity (§197 and 238); it will be our next object to inquire into the nature and properties of this important agent. The union of light and heat exists in the greatest perfection as they are projected from the sun. These two constant associates in the sunbeam radiate in all directions from the glorious centre of our system, and spread themselves, like gravity, through space with an intensity decreasing as the squares of the distances increase.

LIGHT.

§ 359. The cause of that impression upon our eyes, which excites in us the sensation of light, is, like that of heat, to be traced to various sources. The sun is the great fountain, not only of heat, as we have already remarked, but of this twin emanation from it to the earth, and to all the members of the solar system.

It emanates, also, from terrestrial matter in different states of activity. It is thrown off when certain homogeneous substances act upon one another by the mechanical force of friction; thus, when two pieces of quartz or rock crystal, or two lumps of loaf sugar, are rubbed together, they emit flashes of light in a dark place.

It is generated in still greater abundance when heterogeneous bodies act upon one another under the force of chymical affinity; and all the common means of artificial illumination by lamps, candles, and gaslights, are dependant upon this action.

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* Philosophical Transactions, 1773.

All solid bodies, also, heated to a temperature of about 800°, begin to shine in the dark; and if a current of air at 900°, which is in itself non-luminous, be made to strike upon pieces of metal, earth, &c., it will speedily communicate to them the power of radiating light.

The passage of electricity excites it with a degree of intensity only surpassed by that of the solar ray: and the processes of life are capable of evolving it, as we see in the glow-worm and the firefly.

§ 360. Bodies in such state of action are called self-luminous; but by far the greatest number possess no such property at ordinary temperatures. All bodies, however, though not luminous in themselves, nor capable of exciting any sensation in our eyes, become so on being placed in the presence of a self-luminous body. When a lamp, for instance, is brought into a dark room, not only the lamp is visible, but all the other objects in the room. A sunbeam, again, admitted into a darkened chamber, will only illuminate objects directly in its course; but if any of these be white, as a sheet of paper, the whole apartment will become illuminated by this secondary act or radiation. We have this fact illustrated on the most splendid scale of nature in the heavenly bodies. The sun we have just recognised as the great self-luminous source of the system: the moon and planets possess no such inherent energy, but those parts of them on which the sun shines become for the time luminous, and perform all the offices of self-luminous bodies. Thus we perceive that the communication which we call *light* subsists not only between luminous bodies and our eyes, but between luminous and non-luminous bodies, or between luminous bodies and each other.

§ 361. The investigation of the properties of light constitutes the peculiar province of OPTICS; one of the most splendid and perfect departments of experimental science which the human mind has explored. The radiant force of light produces the sensation of sight by striking against the expanded nerve of vision, the retina of the eye, and the effect produced is not merely transient, but persistent during a measurable interval of time. The eye has, therefore, the power of retaining visual impressions for a sensible period of time; and in this way, recurring actions, made sufficiently near to each other, are perceptibly connected, and made to appear as a continued impression. Hence it is that the act of winking with the eyelids forms no impediment to correct vision.

It has been ascertained by experiment, that the impression which the mind thus receives lasts for about the eighth part of a second; so that any point of light revolving with a velocity sufficient to complete the circle within that time, will not be seen as a fiery point, but as a fiery circle; the impression made by it in every part of its revolution will remain until it comes round again to the spot from which it set out. Thus, if a narrow slit be cut in a circle of pasteboard, from the circumference to the centre, and it be held before the eye, and made to spin rapidly upon its axis, objects will be seen through it as if it were wholly transparent, and only covered with a thin gauze. Many familiar appearances are explicable upon the same principle, and, among others, the magical effects of fireworks, in which revolving jets of flame produce the impression of continuous wheels of fire. Several beautiful illustrations of it have also lately been contrived in the form of toys, which are well calculated to excite wonder, and, it is to be hoped, a somewhat more rational curiosity with regard to their construction.(87)

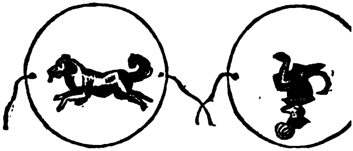
(87) The Thaumatrope, which serves to illustrate this princi-

§ 362. There are two hypotheses wi
the nature of light, which have hitherto
opinions of philosophers.

The hypothesis of *emission* suppose
consists of a highly attenuated fluid, t
of which are not affected by gravity,
dued with a prodigious self-repulsive fo
actually projected from luminous substa
lines, with inconceivable velocity. W
form some notion of matter in such a
we contemplate the direct rays of the
rectilinear course of the light is shown
of floating dust or minute drops of w
are illuminated in its course, and mark
ing direction of its progression.

In the hypothesis of *undulation*, on t
the whole universe, including the inters
of all matter, is conceived to be filled w

ple, is a circular piece of card, on the opposite
are delineated two objects having some relation
The card, by means of two strings fastened to op
its circumference, is made to revolve rapidly, wh
jects will appear united. Thus, in the figure, th
appear mounted on the back of the dog.



The Phantasmascope, or Phanistoscope, is a mo
plication of the same principle. The same object
different parts of the circumference of a large ci
a number of different postures. Between each of
a narrow slit. The back of the card being hel
eye, and a mirror being placed opposite to it, the
to revolve rapidly, when, by vision through the
come before the eye, a constant reflection of the
seen, which will appear to go in succession throu
ferent postures in which it has been drawn.

elastic, rare medium, which possesses the property of inertia, but not gravitation, to which the name of *ether* has been given. This medium is not light, but light is produced in it by the excitation on the part of luminous bodies of an undulatory motion, analogous to the waves of water, or those vibrations of the air which produce the impression of sound upon the ear.

§ 363. A ray of light consists, according to the first hypothesis, of a line of particles projected from the luminous body and impinging upon the eye; according to the second, of a series of undulations excited by the luminous body, which reach the eye, and produce the sensation of light by corresponding vibrations of the optic nerve.

An assemblage of a number of such rays, proceeding together in the same direction, is called a *pencil* of rays.

Having premised thus much upon the hypothetical views of the nature of light, we will proceed to examine the phenomena, and the laws by which they are governed, with as little regard to hypothesis as possible; and we shall speak of a ray of light as of a radiant force, without reference to its nature and the mode of its propagation.

§ 364. Light requires time for its propagation; but the rapidity with which it travels is so great as to be absolutely insensible in such distances as occur on the surface of the earth. It is only when we direct our observations to the celestial bodies, whose distances from us are commensurate with its velocity, that we can appreciate the fact. Astronomy has proved, by the most unexceptionable calculations, that its progress is at the rate of 195,000 miles in a second of time; a velocity which transcends all comprehension; and it is only by reflection, and a comparison with more familiar phenomena, that we can form some conception of it.

" A cannon-ball would require seventeen years at least to reach the sun, supposing its velocity to continue uniform from the moment of its discharge; yet light travels over the same space in seven minutes and a half. The swiftest bird, at its utmost speed, would require nearly three weeks to make the tour of the earth; light performs the same distance in much less time than is required for a single stroke of its wing."*

§ 365. The first relation of light to ponderable matter, which we shall notice, is, that most bodies possess the property of intercepting it in its progress, while a few allow it to traverse their substance. Hence the distinction of bodies into opaque, and transparent or diaphanous. The light of the sun or of a lamp freely reaches us in straight lines through a plate of glass, but is wholly excluded from our eye by the interposition of a plate of metal.

An opaque screen interposed between a luminous body and a sheet of paper or other object, casts what is called a *shadow* upon such object, and the *shadow* is similar in figure to the section of the body which produces it; and hence we learn that the rays of light are transmitted in straight lines. The luminous rays are cut off by the body of the screen, and, being prevented from falling upon the object behind the surface, exactly coincident with its boundary, remain in a state of darkness; but they continue their course beyond its edge, and illuminate the surrounding space.

§ 366. The law of the decrease in proportion to the squares of the distances, may be experimentally proved by means of the shadow of an object; for a board of a foot square, at a certain distance from a light, just shadows a board of two feet square at double the distance, and the latter has four times as much surface as the former; *i. e.*, the light which is concentrated upon the first board would be diffused

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* HERSCHEL'S Discourse.

ar four times the space if suffered to fall upon
second. (See figure 1.)

An accurate photometer, or measure of light, is
ll a desideratum of science. A very simple meth-
of comparing two sources of illumination was
ggested by Count Rumford. They are so ar-
nged as that each may cast a shadow of some ob-
ct, as a stick, upon a plain white surface; the eye
n then form a tolerable judgment of the relative
kness of these shadows. The brighter light,
ich casts the deepest shadow, is then to be re-
ved, or the weaker to be approached, till the two
e equalized; and the distance of the two lights
m the object which intercept their rays being
asured, the relative intensity of the lights will be
the squares of the distances. In this case the
adow of one light is illuminated solely by the
ys of the other, while the surrounding space is
uminated by the rays of both; when the shadows,
erefore, are equal, the lights are equal. The eye,
wever, is not much more to be depended upon for
estimate of light than the hand is for the weight
an object presented to it, particularly when any
ference of colour may tend to perplex the judg-
ent.

267. When a pencil of light traverses space or
perfectly homogeneous medium, its course is
ctilinear and its velocity uniform; but, when it en-
unters an obstacle or a different medium, it un-
rgoes certain modifications, of the nature of
hich we must endeavour to form some distinct no-
tions.

It separates itself into several portions, which
rsue different courses, and are otherwise differ-
ntly modified. One of these portions is *regularly*
flected or turned aside, and, after reflection, pursues
course wholly exterior to the obstacle or new me-
dium; a second portion penetrates the medium, and
more or less *refracted* or bent out of its original

direction; a third portion is *absorbed* o fourth portion is repelled from the sur *diates* itself in all directions.

§ 388. The primary law of reflexion incident and reflected rays, which are a same plane, form equal angles with a p to the surface at the point of incidence erally thus enunciated; the angle of equal to the angle of incidence.(88) same law which governs the collisio moving under the influence of mech whether that motion be of a solid, dir or of a liquid propagating by waves.

If we admit a small sunbeam into chamber, and receive it on a plane poli of glass or metal, we may easily convin

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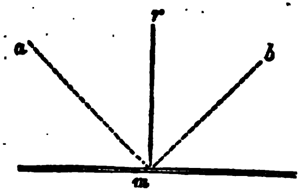


(88) Let ing surface light impin a perpend from *r* to *m* reflected in tion, and r *r*. If the upon *m*, in *m*, it will b *m* to *b*; the tion, *r m b*, measured from the perpendicular, to the angle of incidence, *r m a*, measured fro pendicular.

The reflecting surface may be either plane or latter case, each point of the surface will act small plane.

The elementary optical instruments in which reflecting light is applied, go under the name of are either plane or curved, and of the latter, portions of a spherical surface, either concave most frequently used.

In a plane mirror, an image is seen of an front of it. This image is seen as if it were mirror as the object is in front of it; is erect, size as the object. The image of each point fall from it perpendicularly upon the surface of of the fact by the measurement of the angles. Moreover, to see the image of any object by reflection, it is necessary to place the eye in a situation to receive the rays which proceed from the object at the same angle at which they originally strike the observer.

The greater the angle of incidence, the more light is reflected from all substances, except the metals which reflect the greatest quantity of light at small angles. Even the rough surface of a plaster of Paris cast, or a sheet of hot-pressed writing paper, will afford a very perfect image of an object at a very large angle.

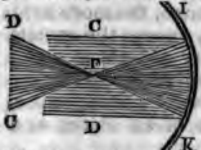
§ 369. All known substances, not excepting air, the most diaphanous of all, reflect some portion of light, and it is calculated that a person plunged 150 feet in the clearest sea would find the light of the sun no more than the light of the moon; and if we look at a luminous object through a transparent piece of glass, we shall find that the object becomes dim in exact proportion to its thickness, so that there is no such thing in nature as perfect transparency. On the other hand, there is reason to suppose that no body possesses the property of perfect reflection; for light penetrates in an inappreciable quantity into the surface of all bodies, and even into gold itself, as it is easy to be assured of by holding a piece of leaf gold between the eye and any strong light, when it will be found to be permeable to bluish rays.

§ 370. Light may be so reflected from regular curved concave surfaces, that all the rays may converge to one point or focus. In this case, the direction of each reflected ray is the same as if it had taken place from a plane surface, tangent to the curve at the point of incidence.(89)

(89) In a concave spherical mirror, the rays which fall upon it parallel are made to converge; if the mirror be a small portion of a spherical surface, and the rays fall nearly parallel to

§ 371. When a ray of light is admitted into a darkened apartment, it may be almost wholly turned.

the axis of the mirror, the converging rays may, without sensible error, be considered as meeting at a point distant half the radius of the mirror from its central point. This point, to which parallel rays are made to converge, is called the principal focus.



Let I K represent the polished concave surface of a segment of a sphere; the pencil of parallel rays, C D, will be reflected from it, according to the law, so as to meet at the point F, where they will also cross one another, and pass on in the same direction to D C. The point F is called the principal focus. If an object be at a great distance, as, for instance, a heavenly body, the rays which proceed from it are to all intents parallel, and an image will be formed of this object in the principal focus. If the object be brought nearer to the mirror, the image will recede, until, when the object is at the distance of radius, the image will be at the same distance. The object being brought still nearer, the image continues to recede, until the former reaches the principal focus, when the reflected rays go off parallel, and no image is formed, or is at an infinite distance. When the object is nearer to the mirror than the principal focus, the image appears as if it were behind the mirror. So long as the image is formed in front of the mirror, it and the focus are said to be *actual*. When the image appears as if it were behind the mirror, they are said to be *virtual*.

So long as the image is actual, it is inverted; when it becomes virtual, it is erect. The relative lineal magnitudes of the image and object follow the inverse ratio of their respective distances from the mirror; and, in consequence, the virtual image seen when the object is near the mirror is always magnified.

In convex spherical mirrors, the focus is always virtual; the image, therefore, appears as if it were formed behind the mirror, is erect, and smaller than the object.

The assumptions in respect to the size of the mirror and the direction of the rays which fall upon it, being only an approximation to the truth, spherical mirrors have no true focus for any kind of rays, and the image is always imperfect. This imperfection goes by the name of the spheric aberration.

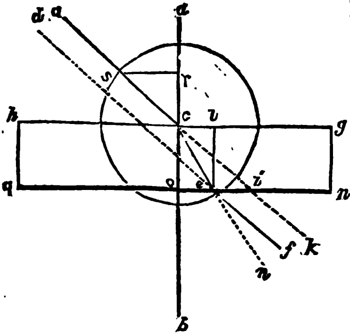
The rays which fall nearest the edges of a spherical mirror converge first, those which fall nearest the centre of the mirror converge latest. Their projection on a plane surface, therefore, forms a species of curve, convex on the side towards the mirror, which is called a caustic.

aside by reflection from a metallic mirror, in any direction according to the angle at which the mirror is presented to it. If it then be made to fall upon any object, it will affect that object as the original ray; one part will be absorbed or extinguished, another reflected, and a third will be irregularly reflected or scattered: it will assume a state of *secondary radiation*. It is this portion which renders an object visible in all directions. This scattered light falling upon other bodies, is again reflected and dispersed from them, and makes all of them also visible, although in a less degree, because of the partial absorption which is constantly taking place, and the whole apartment is lighted. No such general lighting is produced by regular reflexion from the mirror and the effect depends upon the nature of the body on which the rays fall. If it be upon a sheet of white paper, which absorbs but little, the apartment will be well lighted; but if upon black velvet, which absorbs nearly the whole, the apartment will remain dark.

This property is of the utmost importance to vision; it is possessed in various degrees by all bodies on the earth, and very remarkably by the atmosphere which surrounds it. By these means, the light derived directly from the sun is diffused, and that milder radiance maintained which is so agreeable to the eye, and which renders objects visible when the sun's direct rays do not fall upon them. But for this, indeed, all bodies shaded from the sun would be perfectly dark or black, that is, totally invisible; and without an atmosphere, the sun would appear a blazing orb in a black sky. On lofty mountains, when half the atmosphere is below the level of the observer, it is well known that the sun's rays are painfully intense, and the sky is of the darkest hue, almost approaching to black.

§ 372. When a pencil of light falls on the surface of any transparent uncrystallized medium, as water, a portion of it is reflected, and another portion, which serves to make the surface visible, is scattered in all directions; the remainder penetrates the medium, and pursues its course within it. If it enters it perpendicularly, it passes through in a straight line; but if at an angle, it is bent from its course, and is said to be *refracted*. In the reflection of light, the law, as far as regards the direction of the reflected ray, is the same for all reflecting substances: in refraction it is otherwise, and each different medium has its own peculiar action on light; some turning a ray incident at a given angle, more out of its course than others.(90)

(90) If, in this diagram, we suppose a ray of light shot from *a* to *c*, to penetrate the surface of a piece of glass, *g h*, it would reach directly across to *b*; but if the ray fall obliquely, as from *d* to *c*, then, instead of continuing its course to *i* and *k*, it will, at the moment of its entrance, be bent downward into the path *c e*, nearer to a line, *c o*, called the perpendicular to the surface at the point of entrance; and then moving straightly while in the substance of the glass, it will, when it passes out again at *e*, in the opposite surface, be bent just as much as at first in the contrary direction, or away from a similar perpendicular at the surface *i e*, into the line *e f*, instead of the line *e n*. A ray, therefore, passing obliquely through a transparent body of parallel surfaces, has its course shifted a little on one side of the original course, but still proceeds in the same direction, or in a line parallel to the first. An eye, therefore, looking at an object, *d*, obliquely through a piece of glass, *g h p q*, with parallel surfaces, would see it in the direction *f d'* instead of the direction *f d*, and to the left of its real position.



The degree of bending, or refraction of light in traversing a transparent medium, is ascertained by comparing the obliquity of its approach to the surface with the obliquity of its departure after passing, and the ratio of these two angles, when light passes from a vacuum into a given substance, is called the index of refraction.(91)

When light passes obliquely from air into water, the refraction or bending is such, that the line measuring the obliquity before the refraction, or the sine of the angle of incidence, is always longer than the line measuring it after refraction, or the sine of the angle of refraction, by nearly one third of the latter: and the refractive power of water is therefore signified by the index 1 1-3 or 1.33: as, in like manner, the greater refractive power of common glass has the index 1 1-2: that of the diamond, 2 1-2, and so on. Whatever relation holds between a ray and the refraction in any one case, the same holds good in all cases. If, for instance, the obliquity measured by its sine be 40, and the refraction be half, or 20, then in the same substance an obliquity of ten will occasion a refraction of five, &c.

§ 373. Generally speaking, the refractive power of substances is in some degree proportioned to their densities: water, for instance, acts more powerfully than air, and has its power increased by so-

(91) For the purpose of determining the index of refraction, a line is supposed to be drawn perpendicularly through the surface, at the point of incidence, as in the last figure, *a b*, drawn through *c*, and the relative positions of the ray to this line are easily ascertained. Thus, if we strike a circle from the centre *c*, with the radius *c e*, in the plane of the ray *d c e*, the line *r s*, drawn from its point of intersection with the ray before incidence to the perpendicular, will be a measure of the original obliquity or angular distance of the ray, and is called the *sine of the angle of incidence*; and another line, *o e*, drawn from a corresponding point of the perpendicular to the ray after passing, is a measure of the obliquity after refraction, and is called *the sine of the angle of refraction*; by comparing these two lines, the amount of refraction is ascertained.

lution of salt. Glass, again, is superior to either; but Sir I. Newton observed, that inflammable substances had greater refractive powers than others, and he in consequence foretold, what chymistry has since so remarkably verified, that the diamond and water would be found to contain inflammable principles.

Hydrogen, sulphur, phosphorus, wax, turpentine, camphor, and oils, are distinguished by a refractive power, many times greater in respect to their densities than most other substances. Chromate of lead; on the other hand, which is not combustible, possesses the power in an extraordinary degree.

§ 374. Many familiar phenomena might be sufficient to convince an attentive observer of this action of transparent substances upon light. Thus, when a stick is immersed obliquely in water, it appears bent at the point of immersion; and if an object, such as a piece of coin, be placed at the bottom of a basin, and the experimenter place himself so that the side of the vessel may just conceal it, upon pouring water into it, it will become visible.

§ 375. The direction of the refracted ray depends upon the relative position of the surface of the transparent body, not only at its point of entrance, but also at its exit; and thus, by variously modifying the surfaces of refractive media, the rays of light transmitted may be diverted almost at pleasure. By refraction at convex surfaces, for instance, they may be made to converge to a focus, and all their power condensed at one particular point; the refraction taking place as if each ray fell upon a plane surface, tangent to the curve at the point of incidence.(92)

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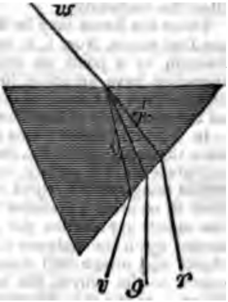
(92) The transparent substance most frequently used for optical purposes is glass. This is ground into a variety of forms, of which the more important are prisms and lenses.

Prisms used for optical purposes are triangular, and affect light in the following manner.

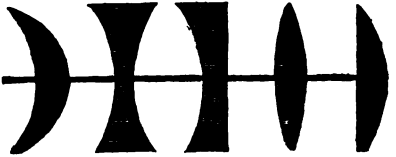
y a proper adjustment of surfaces, the original iation of a ray entering a piece of glass may be bled at its emergence, and some very curious cts produced. The phenomena may be best ob- ved by means of a triangular prism of glass or er refracting substance. The light which falls n one of the faces is refracted at the first sur- e, and also at the second surface; but the second action does not bring the ray into a direction allel with the incident ray, as is the case when surfaces of the glass are allel; but they are per- nently bent into another ction.(93)



the annexed figure, a ray of , *w*, is represented, impinging uely on the upper surface of prism; it is there refracted out e original direction towards a endicular to the surface. On ging from the second surface, farther refracted into the di- on, *g*, away from the perpen- lar to that surface. It is also rated into different portions, of h *v r* are the extremes.

3) Of lenses there are six different forms, each enclosed wo symmetric surfaces, of which one at least is curved. se forms are as follows:

Fig. 1. Fig. 2. Fig. 3. Fig. 4. Fig. 5.



The plano-convex lens is bounded by a plane and a con- spherical surface. Fig. 1.

The double convex lens is bounded by two spherical sur- s, both of which are convex. Fig 2.

**§ 376. The most extraordinary fact co
with the refraction of light is, that a pur**

3. The plano-concave lens is bounded by a plane
cave spherical surface. Fig. 3.

4. The double concave lens is bounded by two sph
faces, both of which are concave. Fig. 4.

5. The meniscus, bounded by a concave and a c
face, and in which the convexity of the latter is greate
concavity of the former. Fig. 5.

6. The concavo-convex lens, bounded also by a co
a convex spherical surface, but having the concavi
than the convexity.

These six forms may be divided into two series. I
the first series, Nos. 1, 2, and 5, parallel rays converg
fraction to a point on the opposite side of the le
therefore have an actual focus. In those of the seco
parallel rays are made to converge, as if they came fro
on the same side of the lens with that on which they

In a double convex lens of crown glass, whose tw
have the same curvature, parallel rays converge to the
curvature of the surface on which they first fall. H
verted image of the object will be found. The object
case at so great a distance as to be considered infinit
the object approaches the mirror, the image recedes,
former reach the distance of a diameter from the lens,
object and image will coincide. On bringing the o
nearer to the mirror, the image continues to recede,
object reaches the distance of a diameter, when no
formed Up to this time the image is inverted. Wh
ject is brought still nearer to the lens, the image bec
tual, is erect, and larger than the object. The relativ
the object and its images are in the inverse ratio of
spective distances from the lens.

The properties of the plano-convex lens are the sa
the exception that the distance of the principal focus,
sequently, of the images, is twice as great as in the d
vex lens. The same is true of the meniscus, with the
that the distance of its principal focus is still great
the plano-convex lens.

The double concave lens makes parallel rays diverg
no actual image; but when the rays which fall upon
fracted, they appear to come from a point twice as f
from the lens as the foci of the double convex lens.
therefore, virtual images, which appear to be forme
same side of the lens with the object; they are erect, ar
appear smaller than the object. Their distance, cons

white light from the sun, admitted into a darkened room through such a prism, instead of being refracted altogether, and appearing still as a white ray, is divided into several rays of different vivid colours. It is thus said to be analyzed or decomposed into its elementary rays. Seven principal colours may be distinguished, viz., red, orange, yellow, green, blue, indigo, and violet: and it is owing to the unequal refrangibility of the rays which produce them that their separation is effected (94). The

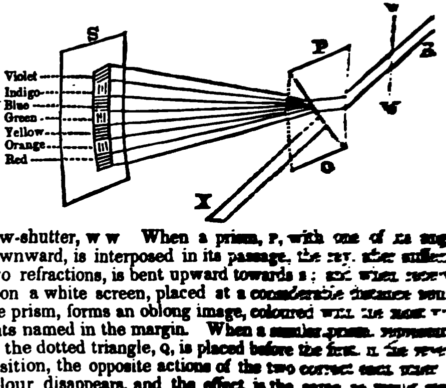
virtual images, is the same as those of the actual images of the double convex lens.

The plano-concave lens has the same properties as the double concave, but the distance of its principal focus is twice as great.

The concavo-convex has also similar properties, but the distance of its principal focus is greater than even in the plano-concave lens.

Lenses have a spherical aberration similar in its effects to that of mirrors.

(94) In the annexed diagram, R X represents a ray of light passing into a dark chamber through a small hole in the window-shutter, W W. When a prism, P, with one of its angles downward, is interposed in its passage, the ray, after suffering two refractions, is bent upward towards S; and when received upon a white screen, placed at a considerable distance behind the prism, forms an oblong image, coloured with the most vivid tints named in the margin. When a similar prism, represented by the dotted triangle, Q, is placed before the first in the reverse position, the opposite actions of the two correct each other and colour disappears, and the effect is the same as would result from the interposition of a piece of thick glass, whose opposite sides are parallel.



relation of the sine of the angle of refraction to the sine of the angle of incidence, differs in each.

TABLE XXV.—*Of the Refrangibility of the Rays of the Spectrum.*

	Water.	Flint Glass.
	Index of Refraction.	Index of Refraction.
Red . . .	1.3310	1.6277
Orange . .	1.3317	1.6297
Yellow . .	1.3336	1.6350
Green . .	1.3358	1.6420
Blue . .	1.3378	1.6483
Indigo . .	1.3413	1.6603
Violet . .	1.3442	1.6711

§ 377. Thus the red ray is the least bent, and the violet the most. This unequal refrangibility is not an accidental circumstance, but is a property inherent in their nature, and which each retains after being subjected to several refractions; and no action of refraction or reflection is capable of effecting their farther decomposition. If they be again collected, as they may be either by refraction through the convex surface of a lens, or by reflection from the concave surface of a mirror, they will reproduce white light at the respective foci.

The space illuminated and coloured by a pencil of rays from the sun thus analyzed, is called the *solar spectrum.*

It is to Newton we are indebted for these beautiful experiments, and for a theory of colours founded upon them.

§ 378. The composition of white light from the

Lenses also separate the light which passes through them, and thus the image which they form, in addition to the natural colours of the object, is fringed around its edges with the seven colours into which white light is separated by the prism. This is a defect of even more importance than that which arises from their spherical figure; it is called the chromatic aberration.

seven prismatic colours may be roughly proved by painting them upon the face of a wheel, and causing it to rotate rapidly. Owing to the permanence of the impression upon the retina of the eye (§ 361) they thus become blended together, and a sort of grayish white is the result. The white is imperfect, because the colours employed cannot possibly be obtained of the proper tints, or laid on in exact proportions.

§ 379. This analysis of white light, however, is not wholly dependant upon the refractive power of a transparent medium, but upon what may be called its *dispersive power:* and different bodies possess very different powers of dispersing or separating the coloured rays of light. If, for example, we make a hollow prism of plates of glass, and fill it with oil of cassia, we shall find that the spectrum which it produces will be two or three times longer than that of a glass prism. Different substances not only exhibit the difference of dispersive power generally upon all the rays of light, but are found to act unequally upon the different rays: thus, if we compare the spectra produced by oil of cassia and sulphuric acid, we shall find that the least refrangible colours, red, orange, and yellow, will occupy less space in the former than in the latter; while the most refrangible colours, blue, indigo, and violet, will occupy larger spaces, or be more expanded.

§ 380. The dispersive powers of dense flint glass and of the lighter crown glass differ very considerably; and it is possible so to adjust two prisms of these substances together that their dispersive powers may correct one another, and yet that a considerable deviation or refraction of the light which penetrates them may remain. It is upon this principle that Dollond first effected the important object of correcting the colours which surround the image of objects in a common telescope. Every simple lens

acts, in some measure, upon light as a
only causing the rays to converge to a
separating them by its dispersive powe
proper adjustment of different kinds o
compound lens may be constructed, in
colour is greatly corrected, and the ray
made to converge in the requisite degree

§ 381. The solar spectrum, however, in
purity, is not, as it appears to common o
to be, an uninterrupted line of light, red
and violet at the other, and shading awa
every intermediate tint from one to the
is interrupted by intervals absolutely da
those parts where it is luminous, the inten
light varies. When viewed in the most
ous way and with proper precautions, i
the appearance of a striped riband, being
the direction of its breadth by an infinite
of dark, and by some totally black bands,
irregularly throughout its whole extent.
are constantly in the same parts of the
and preserve the same order and relati
another: the same proportional breadth
of obscurity, whenever and however exan
vided solar light be used. By solar ligh
understood not only the direct rays of th
the reflected and scattered light from
source, as the light of the clouds or sk
moon or planets.(95) Though similar

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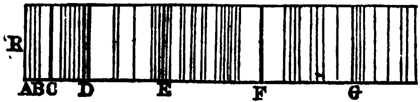
(95) The principal lines in the solar spectrum ar
sented. R is the red extremity, and V the violet;
black line beyond the middle of the red. At D is a
line in the orange, the two being separated by a b
is the middle one of a number in the green. At



observed in the spectra from other lights, as that of the fixed stars or of artificial lights, yet they are differently disposed, and the spectrum of each has a system of bands peculiar to itself. This phenomenon has been ascribed to the action of the solar atmosphere, which may have the property of absorbing particular portions of the rays of light. A similar specific action has been found in different gases and vapours, to which we shall again refer when examining the properties of heterogeneous kinds of matter.

In the spectra from artificial lights, some of the colours are sometimes wanting.

The elder Herschel, in examining the solar ray by means of a prism of flint glass, found the greatest heat in the red ray, or even in the dark space a little beyond it; and concluded that radiant heat was less refrangible than the least refrangible of the rays of light. Professor Seebeck subsequently ascertained that the place of maximum temperature in the solar spectrum depends upon the chymical composition of the substance of which the prism is made. With a hollow prism filled with sulphuric acid, it fell within the limits of the orange space, and with water, within those of the yellow.

§ 382. The decomposition of light may also be effected by absorption: thus, rays of homogeneous colours may be obtained by transmission through glass stained with certain metallic oxydes:

Homogeneous red . .	Oxyde of copper.
" blue . .	" cobalt.

But more ordinarily the colours of natural objects are compounded in several rays, which are left after the absorption of others.

strong black line in the blue. G is in the indigo, and H is the most remarkable one in the violet. Between these, others are situated so thickly that the number of the whole amounts to about 590.

§ 383. Thin plates or scales of different substances, or substances divided by fine regular lines, or consisting of minute fibres, have also the property of decomposing light which falls upon them; but the series of phenomena which they present are totally different, and depend upon different principles. The simplest case, perhaps, of this curious property occurs, if we allow a small beam of divergent light to enter into a dark room by a hole not more than 1-40th part of an inch diameter, or, better still, through a small convex lens, and place a thin rod of any kind of matter, such as a pin, in its course; if we then examine its shadow, we shall find that on both sides of it there are fringes of coloured light, the colours being as follows, looking from the shadow:

First fringe . . .	Violet, indigo, pale blue, green, yellow, red.
Second fringe . . .	Blue, yellow, red.
Third fringe . . .	Pale blue, pale yellow, red.

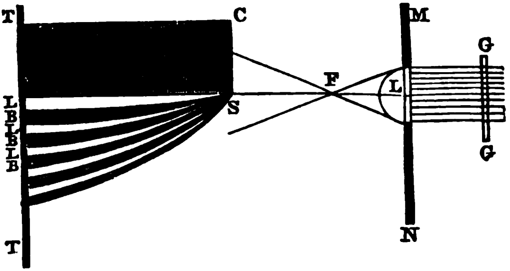
§ 384. If, instead of white light, any of the homogeneous rays of the spectrum be observed in the same way, the fringes will be of the same colour, and their intervals black.

If we now examine the shadow itself, we shall find that it also is divided by parallel fringes, which vary in number and in breadth according to the distance of the body from the shadow that is examined.

Now these phenomena must depend upon light *bent* somehow or other into and towards the shadow, and the name of *inflection* has been employed to distinguish them. The name of *diffraction* has also been applied to them.

If a screen be placed on one side of the inflecting body, and a little behind it, so as to cut off the access of light to that side, the light will pass by on the other side, but all the fringes in the shadow will disappear; proving that the fringes in the shadow are occasioned by the *interference* of the rays bent into the shadow on one side of the body, with the rays bent into the shadow on the other.(96)

(96) Let a pencil of rays pass through a glass, G G, of homogeneous colour, and fall upon a lens, L, of short focus, fixed in a diaphragm, M N. Place at a little distance from the focus a screen, C S, with a thin fine edge, and receive its shadow on a white screen, T T. The line F S L, which would be the boundary of the geometrical shadow, will not be the real separation of light and shade. The shadow itself, on the upper side, will not be totally dark, but will be sensibly illuminated by a faint light, gradually shadowing off; and below will be observed *fringes*, or alternations of light and dark. The first is a bright band, L, parallel to the edge of the screen, then a dark fringe, B, parallel to the former. This is called the black fringe of the first order; then again a second bright band, and then a black one, which is called the black fringe of the second order; and so on successively till black fringes may be observed, under favourable circumstances, of the sixth and seventh orders. The bright bands become less and less brilliant, till they are confounded with the light which passes by the edge of the screen.

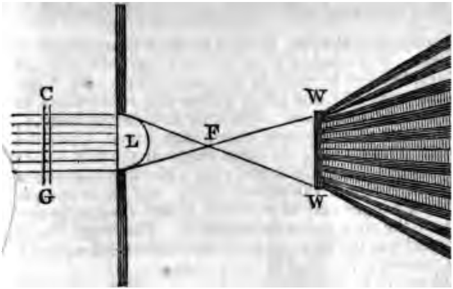


All the colours of the spectrum produce this effect, with only this difference, that, in passing from the red to the violet, they become narrower and narrower. It is for this reason that white light does not give black and white fringes, but fringes of different colours arising from the mixture of the prismatic colours in different proportions.

The different fringes have their origin in the edge of the screen; and by tracing them at different distances of some yards from this origin, it is found that they propagate themselves in hyperbolic curves, as represented upon an exaggerated scale in the preceding diagram.

§ 385. "The law of this interference ma
explained. Let us suppose two minute p
light, radiating from two points close to one
to fall upon the same spot of a piece of
which case they may be said to interfere
another (for, if the paper were removed, th
cross one another at that point). Then, if th
of their paths (or the distances between t
and the two radiant points) are the same,
form a bright spot or fringe of light, havi
tensity greater than that which would h
produced by either portion alone. Now it
that when there is a certain difference bet
lengths of their paths, a bright fringe is p

The concentration of the light by a lens is not n
the phenomena.

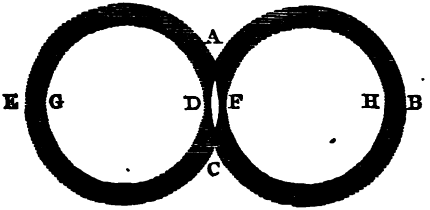


Supposing the arrangement to be as before, only tha
distance from the focus, a hair or fine wire, w w, be
the course of the rays, its geometric shadow would r
on the screen, T T. Beyond this, on each side, s T, s′
may be observed analogous to those arising from the
screen. These are called *exterior fringes*.

But, in addition to these, *interior fringes* may be obse
pying the whole width of the shadow. As before, th
ger in red than in violet light, &c., and, consequently,
light present colours of various tints.

exactly similar to what is produced when their lengths are equal. If we represent this difference by the letter *d*, then similar bright spots or fringes would be produced, when the difference in the lengths of the paths are 2 *d*, 3 *d*, 4 *d*, 5 *d*, &c.; but, what is very remarkable, it is clearly proved, that if the pencils of light interfere at intermediate points, or at 1-2 *d*, 1 1-2 *d*, 2 1-2 *d*, 3 1-2 *d*, then, instead of adding to one another's intensity, the two pencils of light destroy one another, and produce a black spot or fringe."(97) The distances at which these interferences take place are different for the different coloured rays of the spectrum; and hence, although with homogeneous light, the fringes are only of the colour of the inflected ray alternating with black, when compound light is employed, they consist of various mixtures of the rays in a definite order.

(97) If light be allowed to enter into a dark chamber by two small pinholes, placed at such a distance that the cones of rays only intersect one another at a certain distance, and it be received upon a white screen, the shaded circles in the annexed figure will define the limits of the illuminated spaces; the common segment A F C D will be much more illuminated in its interior than any other part, and the arcs A D C and A F C will be of remarkable blackness, although they receive more light than the rest of the circumferences of which they form a part.



If one of the holes be closed, the points in A D C or A F C become more brilliant, although deprived of the additional light from the second hole. Light added to light thus produces darkness, and an obscure space becomes lighted by the abstraction of light.

§ 386. In giving even the most superficial of these interesting phenomena, it is almos sible to avoid alluding to the two rival the light, for the purpose of remarking that the tory hypothesis explains them in the most tory manner, and taking either the analogy undulations, or the musical vibrations of two we shall find similar interferences occurring. a system of waves on water interfere with other at certain intervals, the force of one to the force of the other, and the height of th is doubled; but when they interfere at inter intervals, the rise of one corresponds with of the other, and both are obliterated. Or t of alternate cessation and increase of soun is produced by two musical notes nearly in and which is known by the name of *beats*, a striking analogy with the alternate lumin black fringes arising from the interference

§ 387. Thin plates of different substances analogous phenomena of colour by the inte of the rays reflected from the second surfac plate with the light reflected from the first This may be very well exemplified by thin s mica, which may be procured of any degre nuity by splitting the edge of the plate, and th ing it asunder with a sharp pull. The col pend upon the thickness of the plate, and a the simple colours of the prism. Whatev are thus produced by reflected light, the mentary tints, or those colours which are to constitute white light by mixture with the be found in the light which is refracted throug The same effects are produced in a very b manner in soap-bubbles, which, as they gro ner by evaporation, exhibit a series of th splendid colours. A drop of oil thrown upo face of water, or glass blown very thin, p similar results.

The iridescent colours which are seen upon the surface of *mother-of-pearl* are referable to fine parallel lines formed by its texture; and are produced, in a minor degree, even by the surface of sealing-wax, upon which their impression has been taken. The splendid and variable colours of the plumage of many birds is also dependant upon their fibrous arrangement; while in the gorgeous colours of shells and fish, we see the effects of a thin laminated structure.

§ 388. But the most beautiful illustration of the subject is the coloured rings of Newton, the laws of which were illustrated by that unrivalled philosopher.

He placed two convex lenses of long focal lengths above one another, so as to touch at their summits. They were kept together by three pairs of screws, at equal distances from each other, so as to produce regular pressure at the point of contact. A regular system of circular rings appeared round this point, having a black spot in the centre; each spectrum, or order of colours, consisting of fewer colours as they receded from the centre. The order of the colours of the thin plate of air included between the glasses is given in the following table, both for reflected and for transmitted light:

TABLE XXVI. *Colours of Newton's Rings.*

	Reflected Light.	Transmitted.
FIRST SPECTRUM .	black.	white.
	blue.	yellowish red.
	white.	black.
	yellow.	violet.
	orange.	——
	red.	blue.
SECOND SPECTRUM .	indigo.	white.
	blue.	yellow.
	green.	red.
	yellow.	violet.
	orange.	——
	red.	blue.
	scarlet.	——

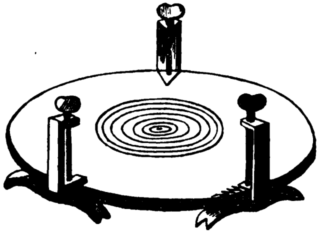
THIRD SPECTRUM .	purple.	green.
	indigo.	—
	blue.	yellow.
	green.	red.
	yellow.	—
	red.	bluish green.
FOURTH SPECTRUM .	bluish green.	red.
	yellowish green.	—
	red.	bluish green.
FIFTH SPECTRUM .	blue.	red.
	red.	
SIXTH SPECTRUM .	blue.	
	red.	
SEVENTH SPECTRUM	greenish blue.	
	white.	

Sir Isaac Newton ascertained in this way, by direct measurement, that air at and below a thickness of half a millionth of an inch ceases to reflect light, and at and above a thickness of seventy-two millionths of an inch it reflects all the rays of the spectrum. Between these two limits it reflects the various orders of colours set down in the table.

Water at and below a thickness of three eighths of a millionth of an inch ceases to reflect light; at and above fifty-eight millionths it reflects white.

And glass transmits all light at a thickness of one third of a millionth of an inch, and reflects all at and above fifty millionths of an inch.(98)

§ 389. The law of ordinary refraction, which we



(98) The arrangement of the lenses is here shown, with the coloured concentric rings arising from the thin film of air enclosed between them: and in the annexed figure they are exhibited in section; the proportion of the curvatures being much ex-

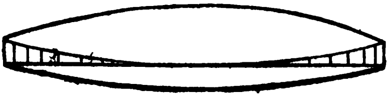
have hitherto considered, is very far from general, and it only obtains where the refracting medium belongs to one or other of the following classes:

1. Gases or vapours.
2. Liquids.
3. Bodies solidified from the liquid state so suddenly as not to admit of regular crystalline arrangement, such as glass, jelly, gums, resins, &c.
4. Crystallized bodies of that class which may be supposed to be constructed of spherical particles, such as the regular cube, octohedron, &c.

These solid bodies even cease to belong to this class when they are forcibly compressed or dilated, either by mechanical force or the unequal action of heat. All other bodies, such as salts, crystallized minerals, all animal and vegetable bodies in which there is a tendency to regularity of structure—as horn, quill, mother-of-pearl, &c.—act upon light in its passage through them in a very different manner. They divide the refracted portion into *two distinct pencils*, each of which pursues a rectilinear course within the medium, according to its own peculiar law.

§ 390. The best exemplification of this mode of refraction is to be found in a substance called Iceland spar. It is perfectly transparent and colourless, and susceptible of a high polish. It may be cleaved or broken into solids of a rhombic form, and the natural faces are generally even and perfectly polished.

aggerated, in order to show the gradual increase in the thickness of the film.



If we take a rhomb of this substance, and look at a small illuminated object through it, or a line of light passing through a slit in an opaque plate, or a black line upon a sheet of paper, in certain positions, two images of the object will appear; and upon turning the rhomb round in its own plane, so as to make a complete revolution, the two images will assume a regular movement with regard to each other, so that one will fall upon the other, or coincide with it twice in the revolution; and it will be easy to ascertain that these coincidences take place in two positions of the spar, which are directly opposite to each other. The maximum separation occurs at the two intermediate points of the revolution, and the distance is proportioned to the thickness of the rhomb.(99)

Hence it appears that a ray of light, in passing through Iceland spar, is split into two by some force residing in the crystal.

§ 391. Now the line which joins the obtuse angles of such a rhomb is designated as the axis

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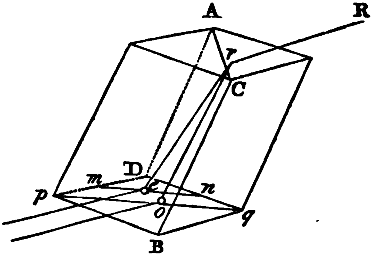
(99) If we place the rhomb, as in the annexed figure, above a sharp line, the line will appear doubled, as *m n*, *p q*; or a dot will be doubled, as *e o*. If we cause a pencil of light, R *r*, to fall upon the surface of the crystal, it will be separated into two rays, *r o*, *r e*, which will respectively emerge at *o* and *e*, in the directions *o o'*, *e e'*, parallel to R *r*. The same phenomena



of the crystal, and it is also the optic axis of the mineral. Whenever a ray of light passes along this axis, or the principal section or plane of the crystal in which it is contained (and which may be conceived to contain an infinite number of the similar axes of the primitive molecules of which it is composed), it passes whole and undivided; and if two artificial planes be ground parallel to one another, and perpendicular to the axis, an object will appear single when viewed perpendicularly through them. In all other directions the ray will be divided into two, one of which follows (nearly) the laws of ordinary refraction, and may be denominated the *ordinary* ray: the other varies from those laws, inasmuch as in general its plane of refraction does not coincide with the plane of incidence, and the sines of incidence and refraction cease to have a constant relation to each other: it is distinguished as the *extraordinary* ray. The sines of incidence and refraction, however, of the extraordinary ray, are always constant in the same substance at the point of greatest deviation, which happens when the ray passes along a plane at right angles to the axis of the crystal; and in certain substances the index of refraction of the extraordinary ray is sometimes greater, and sometimes less, than the index of refraction of the ordinary ray. Hence crystals have been distinguished as repulsive and attractive, or negative and positive crystals.

There are crystals of other substances, again, which present two optic axes, along which a ray of light can penetrate without being divided: but the position of these cannot conveniently be determined with regard to the crystallographical axis.

will occur by making the ray R *r* fall at the same incidence, and in the same direction relatively to the summit A, upon any point of the faces. The plane, A *c* B D, is called the principal section of the crystal, and the axis, or the line which may be drawn from the solid angle A to the angle B, is contained in it.

§ 392. If the rays of light which have been separated by passing through a crystal of Iceland spar be made to pass through another crystal placed similarly to the first, there will be no further subdivision of the light; the two images will be merely separated to a greater distance from the increased thickness through which the rays pass. If, again the two crystals be so placed that the principal sections are at right angles to each other, there will be still but two images; but the ray, ordinarily refracted in the first, will become extraordinary in the second, and the extraordinary ray will become the ordinary. But at all intermediate positions of the two crystals there will be a subdivision of each ray; and, consequently, four images. These four images will be of equal intensity when the principal sections of the two crystals are at an angle of 45° to each other; at all other angles one or other of the images diminishes in intensity as the principal sections approach to a perpendicular or parallel position.

Each ray emerging, then, from a crystal of Iceland spar, is only subject to a further division in particular positions of a second crystal; whereas natural light is always divided into two portions of equal intensity. Each ray has suffered a physical change; it is not acted upon by the force of the second crystal as natural light would be, but requires that the force be applied in a particular direction, relatively to the modification it has received from the first crystal.

§ 393. This physical change has been called *polarization* (a term derived from hypothetical considerations of the supposed arrangements of the poles of the molecules of light upon the theory of emission, but which must now be considered merely as a conventional term to express a class of phenomena). There are many crystallized minerals which, when cut into parallel plates, are sufficiently transparent to allow abundance of light to pass through them with perfect regularity, which, upon its emergence, is found to have acquired the peculiar modification here in question. One of the most remarkable of these is the *tourmaline*. If we take a well-polished plate of this mineral, of moderate thickness, cut from a crystal of a brown colour, in a direction parallel to the axis of the prism, a candle may be seen through it as through a plate of coloured glass; and no change will be observed upon turning it round. If another similar plate be interposed between the first plate and the eye, and turned slowly round in its own plane, the candle will appear and disappear alternately at every quarter revolution of the plate, passing through every gradation of brightness, from the maximum to a total, or nearly total, evanescence, and then increasing again by the same degrees as it diminished before. If we attend to the position of the second plate with respect to the first, we shall find that the maximum of illumination takes place when the axis of the second plate is parallel to that of the first.

§ 394. If we examine the two pencils of light after separation by a crystal of Iceland spar, by means of a plate of tourmaline, we shall readily perceive that the ordinary image (that which is not deviated from the axis of the crystal) acquires its greatest intensity when the axis of the tourmaline is perpendicular to the principal section of the rhomb, and that it becomes extinct in the opposite direction. When the axis of the tourmaline lies in the principal section itself, the extraordinary image (that which lies out of the axis and deviates from it) presents phenomena exactly the inverse of the former.

§ 395. The polarization of a ray of light may also be effected by reflexion. It takes place at a certain angle of incidence (which is therefore called the polarizing angle), which is different for different substances. When a ray of light is made to fall upc a polished glass surface, at an angle of 56° 45′, tl angle of reflexion will, according to the general la be equal to the angle of incidence; and if, in this p sition, it be viewed through a plate of tourmaline, will exhibit the same series of phenomena as if had been passed through another plate of the san substance. The light is extinguished when tl axis of the tourmaline is parallel to the plane of r flexion.

If, instead of viewing the reflected ray through tourmaline, we place another plate of glass so th the reflected ray may fall upon it at the same ang as upon the first, this second plate may be made turn round its axis without varying the angle whi it makes with the ray which falls upon it. Wh the two planes of reflexion are parallel to each ot er, the ray of light or luminous object will be r flected from the second glass in the same mann as from the first; but if we turn the second gla round a quadrant of a circle, so as to make the r flecting planes perpendicular to one another, tl whole of the ray will pass through the second gla and none of it will be reflected. Let us turn tl second glass round another quadrant, so as to mal the reflecting planes again parallel, and the ray w be again wholly reflected. When the glass h been turned round three quadrants, the light will again extinguished.

As. both the pencils of light, into which a ray divided by passing through a rhomb of Icela spar, are polarized, but in opposite directions, viewing the reflexion of a lamp from glass, at t proper polarizing angle, through such a crystal, t two images will alternately appear and disappear it is turned upon its axis.

§ 396. It may perhaps assist our comprehensi of the connexion of these phenomena to illustra them by a rough analogy: a ray of common ligl as it is emitted from a self-luminous body, we may conceive to revolve upon an axis coincident with its own direction, as a cylindrical rod may be made to turn, or, which comes to the same thing, the reflecting or refracting surface may be made actually to revolve around the ray, as an axis, preserving the same relative position to it in all respects, and no change in the phenomena will be perceived.

But if, instead of employing such a ray of ordinary light, we subject to the same examination a ray which has been subjected to the action of certain material bodies, and has become polarized in the way which we have just examined, we find this perfect uniformity of result no longer to hold good. It is no longer indifferent in what plane, with respect to the ray itself, the reflecting or refracting surface is presented to it. It seems to have acquired sides, a right and left, a front and back, and to be no longer like the cylindrical stick, but like a four-sided one. If we imagine a surface to be made up of detached fibres, all lying in one direction, or of scales or of laminæ arranged parallel to one another, we should find no difficulty in thrusting the cylindrical stick through such an arrangement in any direction; but a flat ruler would only penetrate it in one direction.

The two rays of light, polarized in opposite planes, after emerging from a rhomb of Iceland spar, may be represented by two such rulers presented to the bars of a grating, in opposite directions; while the thin edge of one passed freely between them, they would present an impassable barrier to the other, which would be presented to them crosswise. Supposing the grating to revolve upon its axis, on the completion of the first quadrant, the first would be arrested, and the second would pass; and so they would alternately pass and be stopped at each quadrant of the turn.

We find, however, in Professor Wheatstone's experiments, to which we have before referred, a much more refined and natural analogy to the phenomena of polarized light in sound. We have already seen that, when a tuning-fork is connected with one extremity of a straight conducting-rod, the other end of which communicates with a sounding-board, on causing the fork to sound, the vibrations are powerfully transmitted. But, on gradually bending the rod, the sound progressively decreases, and is scarcely perceptible when the angle becomes a right one. As the angle is made more acute, the phenomena are produced in an inverted order; the intensity gradually increases as it before diminished; and, when the two parts are nearly parallel, it becomes as powerful as in the rectilinear transmission. By multiplying the right angles in a rod, the transmission of the vibrations may be completely stopped.

To produce these phenomena, it is necessary that the axis of the oscillations of the tuning-fork should be perpendicular to the plane of the moveable angle; for, if they be parallel with it, they will be still considerably transmitted. Professor Wheatstone placed a tuning-fork perpendicularly on the side of a rectilineal rod; the vibrations were therefore communicated at right angles; when the axis of the oscillations of the fork coincided with the rod, the intensity of the transmitted vibrations was at its maximum; in proportion as the axis deviated from parallelism, the intensity of the transmitted vibrations diminished; and, lastly, when it became perpendicular, the intensity was at its minimum. In the second quadrant the order of the phenomena was inverted, and a second maximum of intensity took place, when the axis of the oscillations had described a semi-circumference, and had again become parallel, but in an opposite direction. When the revolution was continued, the intensity of the transmitted vibrations was varied in a similar manner; it progressively diminished as the axis of the oscillations deviated from being parallel with the rod, became the least possible when it arrived at the perpendicular, and again augmented until it remained at its first maximum, which completed its entire revolution.

§ 397. This state of polarization once acquired by light, is retained by the ray in all its future course (provided it be not again modified by other bodies); for it matters not how great the distance between the substance operating the change and the substance by which it is afterward analyzed, whether they be in contact, or many inches, yards, or miles asunder, not the least variation can be perceived in the phenomena in question.

§ 398. Different substances polarize light by reflexion at different angles.

The angle for	Glass	is 56° 45′
"	Water	53° 11′
"	Rock crystal	56° 58′
"	Iceland spar	58° 51′
"	Sulphur	63° 45′
"	Diamond	68° 1′

§ 399. Light may also be polarized by successive reflexion from the different surfaces of several plates of transparent substances at other angles, as, for instance, from a pile of five or six glass plates: and the portion which in this case penetrates through the pile, is found to be exactly equal to the former, and also to be polarized, but in the opposite plane.

§ 400. But the most interesting, as well as the most splendid, of all the phenomena of polarized light, are the vivid and gorgeous colours which are developed by the action of crystallized plates under certain conditions. If a ray of light, polarized in any of the ways which we have described, be made to traverse a thin plate of mica or sulphate of lime, which is perfectly diaphanous and colourless to common light, and then analyzed by a plate of tourmaline in that position in which, without the plate, it would wholly disappear, the ray will appear, but coloured in the most splendid manner with different tints, dependant upon the thickness of the plate: the tint will also vary with different degrees of inclination of the plate; these, in fact, being equivalent to different thicknesses. There are, however, certain thicknesses dependant upon the nature of the crystallized plate, beyond which the phenomena are not produced.

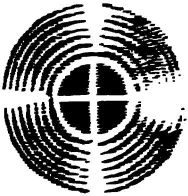
If the analyzing plate be now turned upon its axis, the ray will exhibit at the first quadrant the complementary colour, or that colour which, if superimposed upon the first, would produce white light; but, upon continuing the rotation, it will reappear at the position opposite to the first with the original tint. It thus appears that the original polarized ray suffers a bifurcation or *bipolarization* by its passage through the crystallized plate, and that its plane of polarization is altered. This splitting of the polarized ray differs from that which takes place when the rays pass from a rhomb of Iceland spar into another with its axis at right angles to the first: for, in the latter case, all the rays are equally divided in the two pencils, and constitute white light, while in the former the colours of two halves of the spectrum are combined in the oppositely-polarized rays.

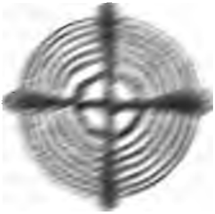
§ 401. These phenomena appear more striking when the analysis of the ray is made with Iceland spar, for then two images are seen together of complementary colours; and they are proved to be complementary by their producing white light at the point at which they coincide or overlap each other.

§ 402. When the original polarized ray is made, however, to pass along the optic axis of the crystallized plate, it exhibits none of these phenomena.

Another [illegible] themselves [illegible] made to [illegible] tallized [illegible] examined [illegible] concentric [illegible] vivid colo[illegible] aspect [illegible] the axis of [illegible] of polariza[illegible] tiful black [illegible] tance. [illegible] opposite [illegible] by a white [illegible] will be com[illegible]

(100) These [illegible]





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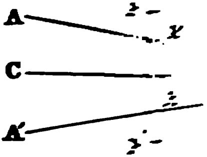


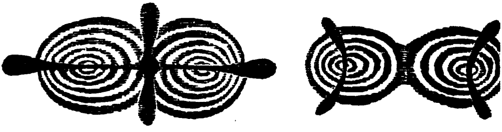
nous cone, O B B'. [illegible] base, B B, has a [illegible] which the axis [illegible] different rays of [illegible]

§ 403. Iceland spar (or calcareous spar) preser this phenomena in great perfection, but all oth crystallized bodies with one axis, of double refra tion, exhibit similar systems of rings. It is, howe er, very remarkable, that some crystals exhibit tl action in opposite directions. Thus, if we take system of rings formed by ice or zircon, and coı bine it with a system of the same diameter form by Iceland spar, the two systems will destroy o another; and hence it is concluded that the syste of rings produced by these crystals are positive opposite in character to the negative system of rin in calcareous spar.

§ 404. Crystals which have two axes of dout refraction present double systems of rings wh examined in the same way, and the changes pr duced in the combinations of the black and whi crosses with the coloured rings, when the crysı and the tourmaline are turned upon their axis, a of the most interesting description, but are t complicated to find a place in the cursory glan which it consists with our present design to ca upon this beautiful department of natural philo ophy.(101)

those which lie near the axis, c o, traverse the plate without viation, and are therefore subject to two refractions, ordins and extraordinary; but these two refractions are always acco plished in the same plane, because every perpendicular secti passing by the axis c o, is a *principal* section. Moreover, t different rays, A o, A′ o, equally distant from the axis, suffer ve different modifications in their planes of polarization; and, fr the interference of the rays, so oppositely polarized, present t succession of colours which we have described.

(101) These figures may convey an idea of the phenome



presented by a crystal of nitre, which belongs to the binaxi

§ 405. These phenomena are not only presented by regularly crystallized bodies, but mechanical pressure is capable of conferring a structure which will develop them. Thus the bending of a slip of glass will enable it to act upon polarized light at the part of greatest tension, in the same manner as a crystal of carbonate of lime.

Plates of glass which have been heated and suddenly cooled, present, when analyzed by a polarized ray which has been transmitted through them, rings, and crosses, and coloured tints, which depend upon the form of the plate; a square plate of unannealed glass thus examined presents at its four angles small circular figures separated by a large black cross. These small circular figures also appear at the corners of any rectangle; but the cross is replaced by coloured bands parallel to the greater sides of the rectangle. A round plate exhibits concentric coloured rings, intersected by a large cross; if the circle be ground down to a square, the original disposition of the colours will return; or if the corners of the square be ground off, the circles will make their appearance.(102)

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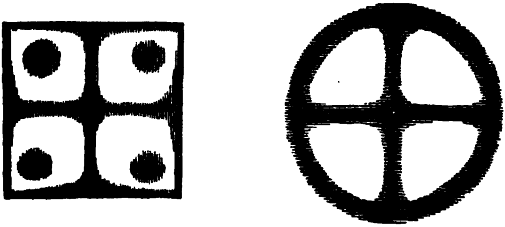
system, subjected to the action of polarized light, in opposite positions of the analyzing plate.

(102) These figures represent the position of the black cross and coloured circles in a square and circular piece of unannealed glass.



In all these cases, upon turning the analyzing plate upon its axis, the colours change to the complementary colours at the opposite quadrants, and the black cross to the white.

§ 406. These effects are due to the forced state of compression in which the particles of the glass are held by the sudden cooling of the outer layer, and they entirely disappear when the glass is perfectly annealed. The direction of the force, and the consequent arrangement of the particles, is altered every time any portion of such a mass, even the slightest, is removed, and thus, by grinding the different figures down to others, the tension is altered in certain directions, and their consequent action upon the polarized ray is also altered. If a square sheet of caoutchouc be stretched at its four corners, and one of them be then cut off, the manner in which it will retract itself from this point will explain, by a rough analogy, the mode in which the particles of unannealed glass are affected by the mechanical removal of any portion of their aggregate.

§ 407. There is one more class of these phenomena to which we must yet refer. If a ray of polarized light be passed through a plate of quartz, cut at right angles to its axis, upon examination it will be found polarized in the same manner as in crystals with one axis, but the place of the black cross will be occupied by colours which fill up the first ring, and encroach upon the rest. These colours vary with the thickness of the plate, but they suffer no change by turning the plate round upon its axis. Suppose the colour in the centre of the rings to be red; let the analyzing plate be turned round from right to left, keeping its inclination invariable, and the red colour will change successively to orange, green, and violet, the analyzing plate acquiring, as it were by its rotation, the power of transmitting these colours in succession; a result which is perfectly explained by supposing that the rays of each of these colours are polarized in different planes.

Upon trying different specimens of quartz, M. Biôt, the discoverer of this species of circular polarization, found several in which the very same phenomena were produced by turning the analyzing plate in the opposite direction from left to right.

§ 408. Upon examining this remarkable property with homogeneous light of different colours, it will be found that, when the yellow ray is transmitted, it becomes fainter and fainter as the plate turns round, till, at a certain angle of rotation, it totally disappears; the homogeneous red ray disappears at a less angle of rotation, and the homogeneous violet at a greater angle.

The rotation of the plane of polarization is proportional to the thickness of the plate for all plates cut from the same crystal: and upon placing two plates one upon the other, which act in opposite directions, the effect will be the same as from a plate having a thickness equal to the difference between the two.

§ 409. Quartz is the only solid substance which has yet been found to possess this property; but some liquids, and even gases, are endued with it.

The essential oil of turpentine turns the planes of polarization from right to left: the essential oil of lemons from left to right. This is the more remarkable, inasmuch as the chymists' art fails to detect any difference in the ultimate composition of these two liquids.

Solutions of camphor in alcohol, and of sugar in water, present the same series of phenomena as quartz, only differing in intensity. The apparatus with which these observations may be made consists of a metallic tube of sufficient length, closed at its two ends with parallel plates of glass. This tube is filled with the liquid to be examined, and a ray of polarized light is passed through its axis, which is subjected at its emergence to the action of an analyzing plate.

The phenomena are more simple when a ray homogeneous light is submitted to the experime and a particular glass stained with oxyde of cop answers the purpose perfectly of stopping all the red ray. The analyzing plate is set in the c tre of a graduated circle, which, turning with it, dicates the polarizing angle with great accuracy a vernier upon its edge. Upon looking thro such an arrangement, no light penetrates the pl except at this angle, which is greater or less, cording to the nature of the liquid, the depth of interposed stratum, or the quantity of the substa in solution.

When liquids are mixed with each other, wh are either inactive or active in the same or oppo directions, the total effect is always equal to the su or the difference of the separate actions. E when they pass into the state of vapour, they ret their power, as M. Biôt ascertained by experime ing upon the vapour of turpentine in long tubes.

§ 410. Here, then, we have phenomena depend not upon structure—that is to say, the positions mutual distances of the particles with regard each other—but upon the nature of the ultim particles themselves. This peculiar action of m ter upon light may even afford the means of dete ing varieties in the nature of substances wh elude the direct means of chymical examinati and M. Biôt has shown that mixtures of the su of the cane and of grapes may thus be recogni nd estimated, which would utterly defy the po ers of chymical analysis.

He has also applied the property with success, a test of the value of different samples of the pressed juice of beet-root in the manufacture sugar, and has thus conferred even a commerc importance upon a discovery which, at first, appe ed to have as little relation as possible to the a or conveniences of life.

§ 411. Another curious application of the properties of polarized light has been made to practical purposes; and such examples furnish an admirable rebuke to those who affect in their ignorance to treat with disdain all such scientific researches as cannot at once, according to their narrow notions, be rendered *useful.*

It is well known that, in dangerous navigations, a commander of a ship will place himself at the masthead for the purpose of more clearly seeing the rocks and shoals at the bottom of the sea. Experience has taught him that from this lofty position they are more visible than from the deck. The reason of this is apparent from the common laws of the reflexion and refraction of light: the greater the angle of reflexion, the greater the quantity of light which is turned aside, and the less that which penetrates. The refracted light from the bottom of the sea is not perceptible amid the glare of that which is reflected to the lower position, for the eye cannot appreciate an addition of less than 1-60th of the whole quantity which affects it: but at the smaller angle from the higher position, the reflected light is so diminished that the refracted portion makes its due impression.

Now this purpose is still more effectually attained by viewing the objects at the bottom of the sea through a polarizing tube; for at the proper polarizing angle, nearly the whole of the reflected light may be extinguished, and they become perfectly visible by their direct refracted light.(103)

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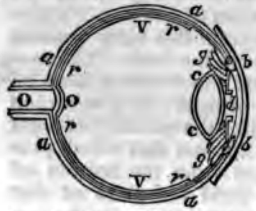
(103) The eye, which is the organ of vision, is in man and many other animals of a globular figure. It differs from a perfect sphere in being somewhat more convex in front and flattened behind. The front part is transparent, and admits light into the interior; this transparent part is called the cornea. In order that the axis of the eye may be directed to the object which is to be viewed, the ball is capable of motion within certain limits, by means of six muscles, arranged in three antagonist pairs. Those of the first pair are applied above and below the eye, and

give it a vertical motion. The two muscles of the se are applied on the two sides, and give the ball a m right to left. These four are called, from their figur the straight or direct muscles. The remaining two the eye around its axis through about a fourth part o and thus, when the head is inclined, the same point is kept uppermost. The motions are performed with est ease, because, although the eye is lodged in a bony interior is lined with a cushion of fat.

The eye is enclosed in a tough membrane called rotic coat, of which the cornea is a part. Within thi ond membrane called the choroid coat, over the surfac is spread a black pai stance, by which all i flection is prevented. terior of the eye is oc three humours. Of is solid, and is suppor middle of the ball by ligaments. This soli the figure of a doub lens, whose surface spherical, and of w hinder surface is mo than the other. This lens is called the crystalline hu is shown in the figure at *c c*. It divides the eye into qual portions, which are filled with liquids. That be lens and the cornea is called the aqueous; that behind the vitreous humour.



It will be seen that light falling on the convex surfa cornea will be refracted or bent from its course, but a b the opposite direction must take place when it reache cave surface of the vitreous humour. Hence the pri fracting effect of the eye will be owing to the crysta By this an inverted image of objects in front will b and, when this takes place upon the inner surface o vision is distinct. In order to receive this image, a n called the retina is spread over this inner surface, and brane is usually admitted to be the seat of vision. T sensible to pain in excess of light, which it is desirable excluded, and is often required to view objects in a f In order that it may accommodate itself to light of di tensities, a screen or diaphragm, having the form of a r terposed at *s s'*, between the cornea and the crystal This diaphragm is called the iris, and is the part wh the distinctive colour to the eye. The opening in called the pupil, and by its contraction or enlargemen less light is admitted. To effect this change the iris is of two sets of muscles, one of which is arranged like radii, the other is composed of a number of concentric rings.

It is supposed by some that this same arrangement is intended for adapting the eye to vision at different distances. In the vision of healthy persons, conscious of no defect, no object, however distant, ceases to be seen, so long as its apparent size is not too much diminished by distance, and objects brought within six or eight inches of the eye are still distinctly visible. If brought nearer than the latter limit they cease to be distinct, and, when close to the eye, produce no other effect than to lessen the quantity of light, or exclude the vision of more remote objects. Objects at different distances are not, however, seen with equal distinctness at the same instant. In fact, we never view more than one object at a time, and for this purpose the axes of both eyes are adapted to it simultaneously. The eye, therefore, has the power of adapting itself to vision at different distances. Many hypotheses, all more or less plausible, have been adduced to explain this operation, but none of them are absolutely certain, and it would occupy too much space to discuss and compare them.

The spherical aberration which affects artificial lenses is not experienced in the eye. This appears to arise partly from the figure of the parts, which are not truly spherical, and partly from the structure of the crystalline lens, which is made up of a number of concentric coats or laminæ, of which the innermost are the densest. The diaphragm of the iris will also serve to aid in obviating this defect by cutting off the extreme rays.

The image formed on the retina is perfectly achromatic, or free from coloured fringes. This is owing to the eye being made up of several refracting bodies, having different ratios between their dispersion and refractive powers, and of which two act in direct opposition to each other. It can be shown that such an arrangement may be so adjusted as to form an image which shall be free from dispersed colours. Artists have partially succeeded in effecting this in optical instruments, but in the eye this correction of the chromatic aberration is complete and perfect.

The eyes of men are subject to two kinds of imperfection, one of which is called long, the other short sightedness. The former arises from the eye not having sufficient power to bring the rays which proceed from near objects to a focus on the retina, the latter from its possessing so high a power that the image of distant objects is formed before the rays reach the retina. In order to remedy the former defect, we make use of convex lenses. These make the rays which diverge from near objects diverge less, and thus fall on the eye under circumstances similar to those which occur when they proceed from distant objects. Shortsightedness is remedied by the use of concave lenses. These have the property of making parallel rays diverge, and

§ 412. Light exerts a very marked, and sometimes energetic, influence upon chymical affinity; determining the combination of some bodies, and the decomposition of others. If a piece of silk be dipped in a solution of chloride of gold, and kept moist and exposed to the rays of the sun, it will gradually change from yellow to green, and then to purple; spangles of gold will make their appearance upon it, and at the expiration of an hour it will be entirely covered with a film of metallic gold. Professor Seebeck steeped a piece of filtering paper in a moderately strong solution of gold, and, cutting it in three pieces, he placed one in a dark place; the second he exposed to the rays of the sun, but placed it also in a dark place before it had undergone any change; the third he exposed fully to the sun. The first underwent no change whatever, while both the second and the third had the gold equally reduced upon them.

A solution of nitrate of silver, in contact with organic matter, undergoes similar changes by exposure to strong light. If a piece of paper be moistened with nitrate of silver, and exposed to the beams of the sun, a very few moments are sufficient to change the colour to almost black: an effect which is well known from its application as an indelible ink for marking linen.

Chloride of silver retains its snow-white colour and lustre if carefully excluded from the light; but, if exposed to the sun, the concentrated light of lime in the flame of the oxy-hydrogen blowpipe, the flame of the voltaic battery, or even to the diffused white light of the clouds, speedily turns to a purplish black colour. This is owing to the decomposition of water, and the formation of muriatic acid and oxyde of silver.

thus causing those which proceed from distant objects to fall upon the eye under circumstances similar to those which occur when they come from an object near at hand.

That these effects arise from the agency of the radiant forces alone, and not from the influence of mere exalted temperature, has been proved by enclosing the several substances in glass covered with black paint, and exposing them to the sun, in which case they became very hot, but, even after several days, no chymical effect was produced.

§ 413. Many years ago it was proposed by Mr. Wedgwood and Sir Humphry Davy to apply this chymical influence of light to the tracing of objects by means of their shadows, or to the copying of drawings by the agency of the light transmitted through them in different degrees. They succeeded in obtaining such tracings by means of paper prepared with nitrate or chloride of silver; but they failed in their attempts to fix them in such a way as to render them afterward unchangeable in the light. Mr. Fox Talbot has lately attained this object; and, by placing prepared paper in a small camera-obscura, he has been enabled, in a few minutes, to obtain most perfect, but extremely small pictures; such as, without great stretch of imagination, might be supposed to be the work of some Lilliputian artists. They require, indeed, examination with a lens to discover all their minutiæ. Engravings and sculpture may thus be copied with the utmost fidelity, and the process appears to be applicable to a variety of useful purposes, such as the delineation of objects in the solar microscope, &c. A process of the same nature was some years ago invented in France by M. Niepsce, and has just been brought forward by M. Daguerre of Paris, who is said to have made some considerable improvements upon it; but neither of these gentlemen have yet published the preserving process in which the great merit of their application consists. This purpose, however, may be effected by washing the paper upon which the design has been imprinted with a solution of *hypo-sulphite* of soda, which dissolves out the unchanged nitrate or chloride, without affecting the dark parts in which the change has been produced. In these *heliographic* drawings, as they have been named, the effects of light and shade are well reversed; but, by a second process, in which the light is transmitted through the first de- upon a second prepared paper, this defect may ectified. In M. Niepsce's process it is understood that the lights and shades correspond with those in nature.

§ 414. The operation of bleaching linen affords er familiar illustration of the chymical changes light is capable of producing. Every wash- man is aware, from experience, that this pro- most readily succeeds in bright weather. The removal of colour is, probably, ultimately referable to the decomposition of water, and the consequent disengagement of oxygen.

§ 415. The instances in which light promotes combination are equally striking.

We have already stated that, when hydrogen and chlorine gases are mixed together, they enter very slowly into combination in a feeble light; but, when exposed to the direct rays of the sun, combination is extremely rapid, and not unfrequently attended with explosion.

Chlorine and carbonic oxyde can be made to unite together by no other influence with which we are acquainted, and hence the product has been called *phosgene gas*. They are introduced for this purpose in equal volumes into an exhausted flask, and exposed for a quarter of an hour to bright sunshine. The colour of the chlorine gradually disappears, and the gases are condensed into half their united bulk. The new gaseous body has an intolerably pungent odour, and greatly affects the eyes. It reddens litmus, and, by contact with water, is resolved into carbonic and muriatic acids. It condenses four times its volume of ammoniacal gas, and the product is a white neutral salt, from which the more powerful acids disengage carbonic and muriatic acids.

§ 416. All the rays of the solar spectrum are not equally endued with this influence upon chymical affinity; for, when they fall upon paper impregnated with chloride of silver, the chloride becomes blackened much sooner in the violet than in the other coloured rays. The power seems to extend even beyond the limits of the violet light itself, as if it belonged to certain highly refrangible dark rays analogous to the little refrangible dark rays of heat at the opposite extremity of the spectrum. These chymical rays may be separated by absorption as well as by refraction: for if a neutral solution of chloride of platinum be mixed with lime-water, and a portion placed in two clear glass tubes, one of which is immersed in a blue solution of ammonia-sulphate of copper, and the other in a red solution of cochineal, oxyde of platinum and lime will be precipitated from the former, while the latter will be protected from all change.

§ 417. The most intense light from the combustion of the hydro-carbons produces no change upon chloride of silver, nor yet on a gaseous mixture of hydrogen and chlorine; but the light from the voltaic battery, and that from lime heated in the oxy-hydrogen blowpipe, when concentrated by a glass lens, speedily blackens the chloride.

§ 418. The processes of *vegetation* are also greatly under the influence of the same subtle agency. The artificial exclusion of light from plants gives rise to the effect upon them which is called *etiolation* or *blanching*. Under such circumstances they always extend their branches and shoots towards any opening at which light is partially admitted; and if this be closed, and another opened in a different situation, they change their direction, and still turn towards the luminous influence. If kept in perfect darkness they become feeble, succulent, insipid, and of a white or yellowish colour; but if in this state they be transferred to a situation where they may enjoy the action of the solar rays, they regain their green colour and become vigorous. According to the observations of Sennebier, the green colour of the leaves of plants is more readily developed under the influence of violet light than under that of any other colour.

§ 419. We will close this summary view of the relations of light to matter with a few observations upon the different degrees with which it seems to be absorbed and retained by some bodies. There are substances which appear to be capable of emitting light at a very moderate accession of temperature, without undergoing any sensible chymical change. The diamond, for instance, fluor spar, and various other bodies, possess this property in various degrees. It is called *phosphorescence*, but is very different from the luminous property possessed by phosphorus, which, as we have seen, is due to a slow combustion at a low temperature. These bodies lose the property of emitting light when they have frequently been made to undergo the process; but may have it restored by passing through them strong electric discharges, which, in some cases, will confer the property upon substances which did not previously possess it. Some species of fluor spar (*chlorophane*) become so light in boiling water as to enable a person to distinguish the letters of a book.

§ 420. Another class of bodies first absorb light from an extraneous source, and give it out again upon being taken into a dark place; these are sometimes distinguished as *solar phosphori*. The most powerful of these is an artificial compound first made by Canton. It may be formed by mixing three parts of calcined oyster-shells in powder with one of flowers of sulphur, and igniting the mixture strongly for half an hour in a crucible. On picking out the lighter-coloured parts, and exposing them to the sunbeams, to common daylight, or to the light of an electric explosion, they will acquire the faculty of shining in the dark, so as to illuminate the dial of a watch and make its figures visible. After a time it will cease to shine; but, if kept in a well-stopped vial, a fresh exposure to the sun will at any time restore the luminous property.

§ 421. Some species of animal and vegetable matter, in a state of decay, have the property of emitting light, particularly some marine fish and crustacea, such as lobsters. The quantity of light given off by such substances is by no means proportioned to their degree of putrefaction; but, on the contrary, the greater the putrescence, the less light they generally emit.

§ 422. The power which certain living animals possess of emitting light at their pleasure properly falls within the province of the science of PHYSIOLOGY for examination and explanation. We have the less reluctance, indeed, to pass over, with a brief allusion, the interesting phenomena which the *glow-worm* and the *firefly* present, inasmuch as they at present remain among the most inexplicable of the products of LIFE. The superficial waters of the ocean sometimes glow with living fire, emitted from countless millions of minute marine animals, who have the privilege of kindling it and extinguishing it at will; while in the eternal darkness of the great deep, to which the rays of the solar orb can never penetrate (§ 369), the larger animals are lighted to fulfil the purposes of their being, by a process which appears at present to be among the most inscrutable wonders of the creation. Our knowledge of *Animal Chymistry* scarcely enables us to form a guess respecting the nature of that light which is thus provided for the submarine hosts of beings.(104)

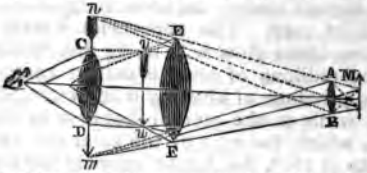
(104) The properties of light, with the modifications which

it undergoes by reflection from polished surfaces, and refractio through transparent bodies, have been used in the constructio of a great number of useful and interesting instruments. I would lead us to too great a length were we to describe all o even the more familiar of them. We shall therefore confin ourselves to the two most important, namely, the Microscop and the Telescope.

The *Microscope* is an instrument by which we view small [illegible]nified. The usual explanation of the action of its [illegible], naming a single convex lens, is as follows:

[illegible] bject is brought near the eye, it appears larger until it ceases to [illegible] seen, in consequence of the rays which proceed from it falling upon the eye with such a degree of divergence that its refractive power is [illegible] ufficient to bring them to a focus on the retina. If no[illegible] vex lens be interposed the divergence of the rays will be [illegible]rected, and the object, being seen at a smaller distance, will [illegible]ar larger. In an eye of usual power, the object will [illegible]n when it is placed in the principal focus of the le[illegible] increase of apparent magnitude will be as much as [illegible]ry limit of distinct vision is greater than the focal di[illegible] lens. It is, however, to be farther considered, that, even at a given distance, an object will appear larger when seen through a convex lens than when seen by the naked eye, in consequence of a change in the direction of the pencils which come from the extreme points. The magnifying power of the single microscope is therefore greater than it would appear from the mode of estimate just pointed out.

The compound microscope has at least two lenses. One of these, C D, is called the eye, the other, A B, the object lens,



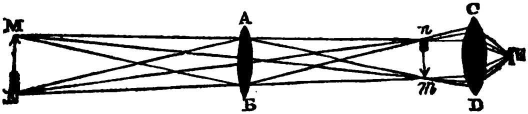
from the position which they respectively hold in relation to the eye and the object. The object lens forms an inverted image of the object, and the eye lens enables us to see this image magnified, and under circumstances suited to distinct vision. Had the compound microscope no other lenses than these two, the extreme pencils, such as *n* E, *m* F, which diverge after forming the image, would not fall on the eye lens, and hence the field of view would be very limited. To increase the field of view, another lens, E F, is interposed between the two others, by which the extreme pencils are caused to fall on the eye lens. This is called the field lens.

With a given eye lens, the magnifying power of the compound microscope is increased by diminishing the focal distance of the object lens. As this involves a diminution in its size, the quantity of light is lessened and the object becomes faint. An equal power, with higher illumination, is produced by uniting two lenses in a piece, to act instead of the single object lens.

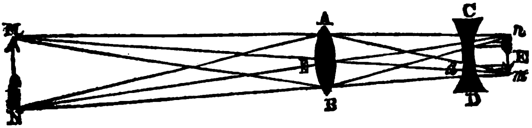
The piece which contains the eye and field lens is capable of being replaced by another combination of two lenses, and thus also a greater degree of illumination may be ensured. These and various other improvements have been made upon the compound microscope within a few years, in the hands of Goring and Chevalier.

The Telescope is an instrument by which distant objects may be seen under an increased angle, and, therefore, as if they were near us. Telescopes may be formed either wholly of lenses or partly of mirrors. The former are called refracting, or dioptric; the latter reflecting, or catoptric telescopes.

The original form of telescope was composed of two double convex lenses. The object lens forms an image of objects in front of it at its focus. This image is viewed by the eye lens magnified, and under circumstances suited to distinct vision. As the object thus seen will appear inverted, its use was in a great degree confined to the heavenly bodies, in which this inversion is of no consequence. It was therefore called the astronomic telescope.

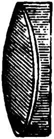


The Gallilean telescope has a double concave eye lens. This is placed so as to receive the rays which have passed through the object lens before they come to a focus and form an image. The effect is therefore as if an erect image existed in the virtual focus of the eye lens. This form is still used in the common opera-glass. The lenses of telescopes, like all others, are liable both to the spherical and the chromatic aberration.



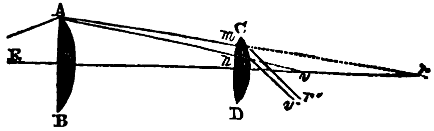
The former is easily remedied by interposing a diaphragm or pierced partition between the two lenses, by which the extreme rays are cut off.

The chromatic aberration is remedied in the object glass by making it of two different kinds of glass. For this purpose a double convex lens is sometimes formed of crown glass, whose surfaces have radii in the proportion of 7: 5. To the least convex surface of this a double concave lens of flint glass is applied, whose surfaces have equal curvatures, and the radii of which are the same as the greater radius of the convex lens. The two united, therefore, have the form of a meniscus, and will form an inverted image of the object; but this image is free from coloured fringes, in consequence of the difference in the relations of the refractive and dispersive powers of the two kinds of glass.

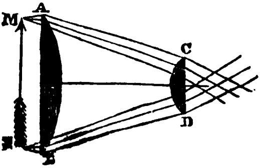


The younger Herschel has, however, proposed a different combination, which is represented in the figure. In this A B is a double convex lens of crown glass. C D a concavo-convex lens of flint glass. The radius of the two surfaces of the crown glass bears to that of the outer surface of the flint glass the relation of 6.72 to 14.2, and the focal distance of the combination is 10.

The chromatic aberration is corrected in the eye-piece by the use of two lenses instead of one. The achromatic eye-piece which is usually employed is represented in the figure. A ray of light falling on the first lens at the point A is dispersed in the directions A *m*, A *n*. These are, by the second lens, rendered parallel, and thus the united colours produce the impression of white light.

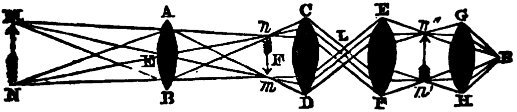


The achromatic eye-piece of Ramsden is composed of two plano-convex lenses, whose curved surfaces are turned towards each other.

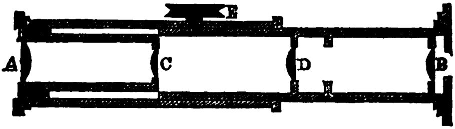


The modern astronomic telescope is therefore composed of a double object lens made of crown and flint glass, and a compound eye-piece. In order to render it capable of viewing terrestrial objects erect, two other lenses are interposed.

It may in this case be considered as made up of two telescopes, by the first of which an inverted image is formed, and by the second of which the erect position is restored.

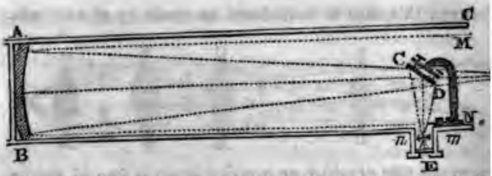


This is completed by substituting for the eye lens, G H, an achromatic eye-piece of either of the forms which have been described. Uhe improved achromatic terrestrial telescope is therefore now composed of five lenses. The achromatic object lens is adapted to a large tube. To this the smaller tube, represented in the figure, which contains the remaining four lenses, is adapted. The lens B sends on the rays, which have crossed after forming an image in the focus of the object lens, in parallel directions. These are caused to form an image in the focus of the lens D, which will be erect; and this image is viewed almost free from colours by the eye-piece composed of the lenses A C.



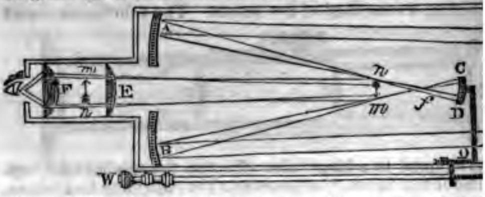
The size of the achromatic refracting telescope was long limited by the difficulty of obtaining pieces of flint glass of sufficient size. In the hands of its inventor its length was therefore limited to ten feet, and of this length no more than a single good one was constructed. A few have been made eight feet in length, but the greater part of the English instruments do not exceed five feet. Of late years the Swiss and German artists have succeeded in making flint glass of much greater size, and thus in increasing the length of the achromatic telescope. The most celebrated instrument in which this has been employed is that constructed by Frauenhoffer for the Observatory at Dorpat in Russia, which has a length of twenty-eight feet.

In the reflecting telescope of Newton, a concave mirror is placed at the end of a tube most distant from the object. By this an image would be formed in the position *n' m'*. Before the rays meet to form this image, they are interecpted by a plane reflecting surface placed at an angle of 45° to the axis of the



tube. By this the rays are bent at right angles, and the ir is formed at *n m*. This image is viewed by an eye lens at

In the reflecting telescope of Gregory, the image forme the great mirror at *n m* serves as an object to a smaller con



mirror. This, therefore, forms a second image at $m' n'$, w will be erect. A hole is pierced through the great mirro which a tube containing an achromatic eye-piece is adapte which this second image is viewed and seen erect.

In the telescope of Cassegrain, the rays which are refle from the great mirror are intercepted by a small convex mi C D, before they can form an image at $n' m'$. The place of

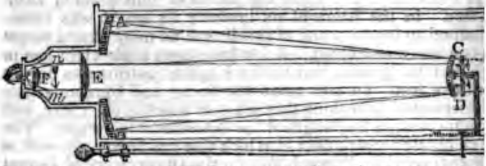


image is thus transferred to *n m*, where it appears inve This inverted image is viewed in the same manner as in th escope of Gregory.

The elder Herschel constructed many Newtonian reflec He also modified their structure by removing the plane refle and bringing the image near to the side of the tube by pla the mirror oblique to the axis of the tube. This image

§ 423. We have referred (§ 000) to the theory which holds that light is conveyed by means of undulations, excited in a medium which occupies all space. It is not our intention to enter into the consideration of the truth or falsehood of that theory, as such discussion would be foreign to our object. We recur to it at present in order to state that this theory derives its strongest evidences from the well-known phenomena of the propagation of sound. The mathematical investigations of the undulatory theory of light are therefore in close connexion with the subject of acoustics, with which we shall close our views of the physical sciences.

ACOUSTICS.

§ 424. We have, in a preceding section, stated some few of the facts in relation to the cause and the manner of the propagation of sound. The origin of sound in the oscillations of elastic bodies may be illustrated by means of a steel plate screwed into a vice. When thus held, it will vibrate if struck. If it be of considerable length, the vibrations will be so slow that they may be counted; and when the efficient length of the plate is altered by drawing it through the vice, it will be found experimentally, as may be also demonstrated mathematically, that there is a fixed relation between the length of the part of the plate which projects from the vice and the number of vibrations it performs. This relation is the same as that between the lengths and the numbers of the oscillations of pendulums. So long as the vibrations of the plate are so slow that they may be easily counted there is no audible sound. The power of counting them ceases

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viewed by an eye-piece. The light in which the original Newtonian instrument, is lost at the second reflection, is here saved. One of the instruments constructed on the last plan had forty feet focal distance. The best made by Herschel is twenty eight feet, and is equal in its powers to the telescope of Dorpat

(§ 000) when they become more frequent than eight or ten in a second; but the law which has been referred to will enable us to calculate their numbers when the lengths of the plates are known. The inference which has been stated (§ 000) is thus made, that at least sixteen vibrations of the sounding body per second are necessary for an audible sound, while, if they exceed twelve thousand per second, the sound becomes inaudible at the other extreme of the scale. Within these limits, then, are included all the sounds audible by human ears. Nor does it appear that any one ear is capable of hearing every sound even within these limits. By experiments made by Wollaston, it appeared that the ear of every person on whom it was made had an imperfection which rendered some sound or other inaudible.

It does not appear that the limits are exactly the same in different individuals of the human race; and other animals have different limits to their auditory scale from those of man. Thus the lion and elephant were found to receive the impression of sound from oscillations too infrequent to affect the human ear, while small animals did not hear the sounds of the lower part of the human scale, and appeared to be affected by oscillations more rapid than any of those which convey the sensation to the human ear.

That the vibrations of sounding bodies are capable of raising waves in liquids, may be shown by the familiar experiment of producing sound in a drinking glass by rubbing the finger over its rim. Series of waves will then be distinctly seen at the surface of the liquid contained in the glass. From facts of this description Newton inferred that the propagation of sound in air resembled that of waves in a liquid. In the latter case no progressive motion is produced, but the waves are formed by an oscillation up and down, resembling the motion of a liquid in a bent tube. The progress of the waves may be illustrated by reference to what takes place in a field of grain, over which waves formed by the wind may be often seen to pass, while each stalk remains firmly rooted to its place.

Taking up this view of the subject, Newton inferred that sounds ought to be conveyed in air at the rate of about 900 feet per second, while the actual velocity, ascertained by careful experiment, is more than 1100 feet.

The cause of discrepancy has been detected by Biôt and La Place, who have shown that the compression of the air which forms the wave changes its capacity for specific heat, and thus renders it more elastic by an increase of its temperature. When this circumstance is taken into account, the theoretic velocity of sound in air is raised from 900 to 1100 feet per second, which agrees almost exactly with experiment.

§ 425. Sound is conveyed by liquids with a greater velocity than in air; thus it passes through water at the rate of 4750 feet per second. In solids the velocity is still greater, being in cast iron ten times as great as in air.

§ 426. The pulses in the air which convey sound are capable of being reflected when they meet with obstacles in their course. These reflected waves will produce separate audible sounds, when they follow the original sound at a sufficient interval of time. If several reflected waves cross each other at the same point within a similar interval, they may produce a sound louder than the original one. This interval, from the constitution of the human ear, is the eighth part of a second, and is therefore equivalent to the passage through a space of about 136 feet.

If, then, there be a vertical obstacle in front of the person who utters a sound, at a distance of about 70 feet, he will hear a distinct repetition of a single syllable, forming what is call lowing immediately after the o distance be doubled, an interv between the original sound and syllables be uttered, there will tion of both. By obstacles greater number of successive s ed, but it will be necessary th should be loud. If a number different distances from the b sound, each will return a separ Such circumstances often exi shores of rivers and lakes.

The best figure to return whence it proceeds, would be sphere of which that point is surface may vary very conside before the interval between th comes so great as to prevent t dible, or even a distinct sound.

The obstacle may be so pl figure, that few or none of the cross or follow each other at s point where the original sound numbers, or even all of them, at the same instant at some case the reflected sound will be mer point, but will be distinct a from distance or intervening o sound may be inaudible. The sesses this property in perfect soid of revolution, and the c are its two foci. It is not nec soid be complete; small portio surfaces lying in its circuit, wi Nor is the ellipsoid the only swer the purpose; any curve reflect the waves in such man to follow each other through short intervals, will return an echo. Among these a spherical vault may be mentioned, in which, if two persons be placed in one of its diameters, and at equal distances from the surface of the vault, the repetition of a whisper uttered by the one will appear as a loud sound to the other. Apartments which have this property are called whispering galleries.

The most remarkable instances of the sort are:

The gallery beneath the dome of St. Paul's Cathedral in London;

The Gothic vault of the Cathedral of Gloucester;

A church at Girgenti, in Sicily, where the sound of whispers near the door is distinctly heard at a point near the extreme end of the church, distant 200 feet;

The Grotto di Favella, at Syracuse, supposed to be the Ear of Dionysius.

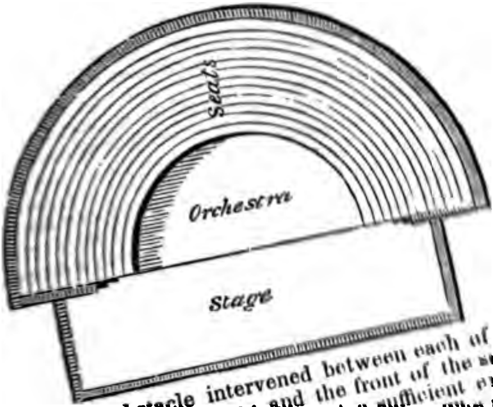
§ 427. Such properties are to be avoided in the structure of buildings and halls in which the human voice is to be exerted or music performed. The human voice, if not strained, is not distinctly audible in free and open space at an average distance of more than 70 feet. But, by the aid of reflecting surfaces, properly placed, it may be made to fill a greater space. Nor is it equally audible in all directions; the distance to which it is carried is greatest directly front of the person who speaks, and least behind him, so that his voice may fill a circle of about 135 feet diameter, in which he is placed 90 feet from the point in front of him, and 45 feet from that behind him.

For deliberative assemblies, conducted according to English and American parliamentary forms, the best figure is probably a parallelogram, and the best arrangement of seats would be parallel to the two longer walls, and rising above each other in steps. The roof and walls should be broken by architectural ornaments, in order to prevent any distinct reverberations. The greatest dimension should not exceed 90 feet. To make the roof of the shape of a dome or regular cylinder is the worst possible method.

Reflecting surfaces near to the speaker aid the voice by joining to the original sound waves which follow it at so small an interval as to make no difference in the sensation they produce on the ear. A distance of 10 or 12 feet deprives them of this advantage, and at 15 or 20 the reflected sound begins to cause confusion, which will be at its maximum when the distance of the obstacle is half as great as that necessary for a distant echo. If the surface, placed immediately behind the speaker, be one which is itself capable of vibrating and emitting a sound, the advantage he will derive from it is the greatest possible. Such an aid to the voice is called a sounding-board. We also find it forming an essential part of many musical instruments, in some of which the sound would be feeble in the extreme were it not adapted to them.

A good form for a room of moderate size, say whose length does not exceed 70 feet, may be constructed by making three of its sides straight and rectangular, like the sides of a parallelogram, and making the fourth side a concave curve. In this case the speaker should be placed in the middle of the curved side, and near the wall. If the greatest length of either of the walls exceed 70 feet, a curved recess may be formed in the middle of one of the longer walls, and the speaker placed in it at a short distance from the wall. In cases where this would be inconvenient, his proper place is in the middle of one of the side walls.

Of all the structures which have been erected for public speaking, the theatres of the Greeks were the best. The part occupied by the audience had usually the shape of a semicircle. The greater part of this was occupied by concentric semicircular seats, rising above each about eighteen inches.



Thus no obstacle intervened between each of the auditors and the stage; and the front of the seats, even when unoccupied, had not a sufficient extent of continuous surface to form an echo. The stage had the figure of a rectangle, applied to the middle of the line which closed the portion of the circle occupied by the audience. The depth of the stage was small, and it was enclosed by walls at so short a distance from the actor as to strengthen the sound by reflection, without causing confusion. In an experiment performed by Dr. E. D. Clarke in the ancient theatre of Halicarnassus, a whisper on the stage was audible in the highest range of seats, at a distance of 150 feet.

The form of an ancient theatre is, on the othe hand, the worst which can be adopted for a delibera tive assembly, as the speakers will occupy th space proper for the auditors, and the advantag will be converted into defects. This does not ply to the French mode of conducting parliamen ry. business, where the speaker ascends a trib which occupies the place of the stage in the Gr theatre. The defect of this form for one of our deliberative assemblies would be enhanced by covering it with a vaulted roof; and, from a combination of the two causes, the Chamber of the House of Representatives at Washington is probably the worst apartment that has ever been constructed for the purpose for which it used.

§ 428. The intensity of a sound that is transmitted by the air depends upon several circumstances:

1. Upon the size of the sounding body; for all other circumstances being the same, the greater the surface, the greater will be the degree of agitation produced in the air.

2. Upon the intensity with which the vibrations of the sounding body are performed; for, the greater the space through which the vibration extends, the greater will be the compression of the air, and the more dense the waves that convey the sound.

3. The number of the vibrations has also an effect; and as sounds approach the limits at which their oscillations cease to affect the human ear, they become less audible. In this respect it appears that other animate beings have a different scale of sounds from man. Large animals appear to derive sensations of sound from vibrations so slow as not to affect the human ear, while animals smaller than man do not perceive those sounds that affect the human ear, and are caused by the least frequent vibrations, while, on the contrary, they perceive sounds produced by bodies vibrating so rapidly as not to affect the auditory nerves of the human race.

4. Upon the distance; sound being conveyed in waves forming a series of spherical shells, it will be obvious that their density and the consequent intensity of the sound must vary in the inverse ratio of the squares of the distance.

5. Upon the density of the air, by an increase in which the intensity of sound is increased. And in the open air, which diminishes in density at in-

creasing altitudes, a sound uttered at a lower level will be better heard than one that reaches the ear in a horizontal direction.

6. Upon the direction in which the impulse is first given; as words spoken through a tube, or the sound of a piece of artillery when fired, are best heard in the direction of their respective axes.

In liquids and solids, the intensity of the sound that is conveyed is increased as well as its velocity; that this should be the case is evident when we consider that the increase in the resistance they offer to compression produces an effect of similar character to that produced by condensing air.

§ 429. The distance at which sounds cease to be perceptible to the ear depends principally upon their original intensity, although the direction they are first compelled to take will have a certain influence. The sound of battering cannon used at the seige of Genoa in 1801 was heard at a distance of ninety miles; and it is on record that those used at the seige of Ostend in 16— were heard in London. In this latter instance the sound was probably conveyed in part by water. Field-pieces were heard at the battle of Jena at the distance of seventy-five miles.

§ 430. The variety of sounds that are audible to the human ear arises from three several circumstances.

1. From the greater or less frequency of the vibrations of the sounding body. On this depends the musical quality of the sounds, which are hence distinguished as grave and acute, flat and sharp.

2. Upon the velocity with which the vibrating particles move, growing out of the greater or less space through which they vibrate; as pendulums of equal lengths, and vibrating in equal times, may describe greater or less arcs.

3. Upon the greater or less simplicity of the vibrations. Few or no bodies, when sounding, vibrate in such manner as to produce no more than one

sound. But one of the sounds they emit may arise from vibrations of greater intensity than the rest, and it will be, in consequence, louder than they are. The others may also have a musical relation to the predominant sound, in which case the effect will be agreeable. On the other hand, a body may emit several sounds of nearly equal intensity, and they may be of a relation incompatible with harmony, in which case the effect upon the ear is disagreeable.

§ 431. In respect to the musical quality of sounds, it is well known from experience, that, unless the vibrations of two or more bodies, or portions of the same body, coincide, either exactly or at short intervals, the effect they produce upon the ear is disagreeable; while, if they coincide at short and regular intervals, the contrary is the case.

If two sets of vibrations be performed in times exactly equal, the effect, when they are emitted together, is the most agreeable of all, and they are said to be in unison. If the vibrations of two different bodies have the relation of two to one, each vibration of one coinciding exactly with every second vibration of the other, the effect of sounding them together is next in the order of agreeable sensation, and the one is said to be the octave of the other. The proportion between the numbers of the vibrations that cause different sounds is called their relation, or an interval.

The other relations that are agreeable are those of 4, 6, 8, and all other multiples of 2 to 1; of 3 and 5, and their successible multiples to one; while the relation of 7 and its multiples is disagreeable, and cannot be employed in music. The relations also of the same numbers to the geometric progression,

$$1 : 2 : 4 : 8 : 16, \text{\&c.}$$(105)

are agreeable, and adapted to a musical scale.

(105) Thus the interval 3-1, 5-1 may become 3-2, 5-4, without injuring their utility; and we obtain the relation

$$\tfrac{1}{1},\ \tfrac{5}{4},\ \tfrac{3}{2},\ \tfrac{2}{1}.$$

The fundamental relations then are, omitting 4-1 as the octave of 2-1,

$$\tfrac{1}{1},\ \tfrac{2}{1},\ \tfrac{3}{1},\ \tfrac{5}{1},\ \tfrac{6}{1}.$$

Musicians, however, have included all these intervals between the relations of 1-1 and 2-1, or within a single octave. This is effected by taking advantage of the circumstance that the sounds are still agreeable when the relation is that of either of the above numerators to the series.

It is not, however, as will be presently shown, ne-

The interval of 5-4 is called the third, and that of 3-2 the fifth of the fundamental sound 1-1. A note with its third and fifth is called a perfect accord; for they produce an agreeable effect, not only when sounded in succession, but when sounded together.

Other notes, however, are necessary in music, which, if not suited to be sounded at the same time with the four that have been noted, will yet produce an agreeable succession of sounds. These are four in number, and may be obtained,

1. By adding two notes that form a perfect accord to the fifth, thus:

$$\tfrac{3}{2}\times\tfrac{5}{4}=\tfrac{15}{8}.\quad \tfrac{3}{2}\times\tfrac{3}{2}=\tfrac{9}{4}.$$

The latter, however, does not fall within the intervals 1-1 and 2-1, and is therefore made 9-8.

2. By adding two notes, that form with the octave a perfect accord, of which the latter is last in order, thus:

$$1 : \tfrac{5}{4} : \tfrac{3}{2} :: \tfrac{4}{3} : \tfrac{5}{3} : \tfrac{2}{1}.$$

Arranging the several notes in the order of the magnitude of their intervals, we obtain,

$$\tfrac{1}{1},\ \tfrac{9}{8},\ \tfrac{5}{4},\ \tfrac{4}{3},\ \tfrac{3}{2},\ \tfrac{5}{3},\ \tfrac{15}{8},\ \tfrac{2}{1}.$$

1st, 2d, 3d, 4th, 5th, 6th, 7th, 8th.

These are also distinguished by letters and names as well as by numbers, as follows:

C, D, E, F, G, A, B, C.
ut, *re*, *mi*, *fa*, *sol*, *la*, *ri*, *ut*.

This series of sounds is called the diatonic scale. It is also called the scale of the major mode, to distinguish it from another founded on a perfect accord, whose intervals are

$$\tfrac{1}{1},\ \tfrac{6}{5},\ \tfrac{3}{2}.$$

cessary to introduce a series of seven notes that have this minor accord for their base.

§ 432. On examining the intervals of the above scale it will be seen that their relations, taken by pairs, are of three different kinds, which may be expressed by

9 : 8, 10 : 9, and 16 : 15.

These ratios are called tones. The first, which has the greatest magnitude, is called a major tone, T. The second, a minor tone, *t*, the third, a hemitone; H. In the scale of the major tone they succeed each other in the following order:

T, *t*, H, T, *t*, T, H.

If a scale were formed upon the minor accord, they would succeed each other as follows:

T, H, T, *t*, H, T, *t*;

which is obviously the same as if the former series were commenced at its sixth interval, and the first five repeated.

§ 432. The eight notes of the diatonic scale are called an octave; and it is obvious that sounds bearing similar relations to each other may be extended throughout the whole range of vibrations that are audible to the human ear, each eighth note forming the basis of a new octave. Nearly all instruments of music have a compass of at least two octaves, and hence include, besides two scales of the major mode, one whose intervals follow in the order of the minor mode and a portion of two others. Hence they are capable of performing music both in the major and minor modes, without any especial and separate provision for the latter.

§ 433. These seven intervals, then, are all that can be admitted in music; but as the compass of the human voice is small when compared with that of audible sounds, so also is the compass of some musical instruments; hence it frequently becomes necessary to choose some other note than C for the fundamental or key-note; but this is impracticable so long as no more than seven sounds and their respective octaves are admitted. To render it possible to take any one of the notes as a key-note, an artifice is made use of. The major and minor tones have intermediate intervals introduced between them, and, as they are five in number, these intervals are of that number also. They are called half notes. They derive their denominations from the note next above or next below them, according to the sound that is taken as the key-note; in the former case they are said to be sharp, in the latter flat. Their denominations are as follows, in the two several cases.

C#, D#, F#, G#, A#
D♭ E♭ G♭ A♭ B♭.

If these half notes be taken in such manner as to make their respective intervals exact, when any one of the notes other than C is taken as the key-note, they will not be exact when another is taken; hence the method is not perfect. A remedy is, however, found in the imperfection of the human ear, which does not distinguish with certainty between two sounds, the number of the vibrations causing which is nearly equal; and, therefore, the imperfection is so distributed among the half notes, that, although neither the major nor minor mode of any note has its intervals exact, none of them is so far from the truth as they would be if the intervals of any other were of the proper magnitude. This method is called temperament, and it varies according to the ear of the tuner or maker of musical instruments. When, however, the human voice is used without the accompaniment of an instrument, or an instrument whose sounds can be varied at the pleasure of the performer is played singly, the half notes may be made exact.

§ 435. We have thus filled up the circle of the subjects usually included under the head of Natural Philosophy. Beginning with the powerful attraction which is exerted at immeasurable distances between the great masses of matter, we have followed the same description of force, if not the same in reality, into cases where the particles of separate bodies, and those of the same body, are caused to cohere by its action. In the latter instance we have found it opposed, and finally counteracted altogether, by the repulsive force of heat. Heat has then been considered in sensible form, and in the latent state in which it influences and determines the mechanical form of bodies, and has been detected in its propagation by radiation throughout space. With this agent we have found electricity in its two modifications most intimately connected; and have found in this last-named agent the power of inducing magnetic action. The mode of action of Magnetism has then been discussed, with its connexions and relations to Electricity and Heat. In the course of our inquiries we have found heat in many cases inseparably united to light, and electricity to be a most powerful agent in causing artificial light. We have, in consequence, been led to consider the properties of Light and the phenomena of Vision. Among the theories which have been laid down to account for the propagation of light, we have found one which assumes that it is conveyed by waves raised in a material substance, and have seen that the motion and laws which are followed by such waves are the same as those which govern the transmission of sound. Our circle of physical subjects has therefore been closed by a brief exposition of the more important facts in Acoustics. We have thus filled up our plan, and hope that this view of the connexion of the physical sciences will not only convey a more full examination of the forces which act upon material substances than can be found in any equal space, but that it may be useful in preparing the mind of students for a more laborious inquiry into the physical sciences in general, and those of Mechanics and Chymistry in particular, which the restricted nature of our plan has excluded from this work. The importance of the subjects which we have discussed cannot be better summed up than in the words of the younger Herschel:

"It can hardly be pressed forcibly enough on the attention of the student of nature, that there is scarcely any natural phenomenon which can be fully and completely explained in all its circumstances without a union of several, perhaps of all, the sciences; and it cannot be doubted that, whatever walk of science he may determine to pursue, impossible as it is for a finite capacity to explore all with any chance of success, he will find it illuminated in proportion to the light which he is enabled to throw upon it from surrounding regions. But, independently of this advantage, the glimpse which may thus be obtained of the harmony of Creation, of the unity of its plan; of the theory of the material universe, is one of the most exalted objects of contemplation which can be presented to the faculties of a rational being. In such a general survey he perceives that science is a whole, whose union is lost in affinity, and which nothing but the imperfection of our nature obliges us to divide. He feels his nothingness in his attempts to grasp it, and he bows with humility and adoration before that SUPREME INTELLIGENCE who alone can comprehend it, and who 'in the beginning *saw everything* that he had made, and behold it was very good.'"

GLOSSARY.

A.

ABSORPTION, from *absorbeo*, to suck up; the power or act of imbibing a fluid.

ACETIC ACID, from *acetum*, vinegar; the acidifying principle of common vinegar.

ACICULAR, from *acus*, a needle; having sharp points like needles

ACOUSTICS, from ἀκούω, to hear; the science which relates to sounds.

ACTION, from ἄγω, to move; the effort by which one body produces, or endeavours to produce, motion in another.

ADHESION, -**IVE**, from *ad*, to, and *hæreo*, to stick; the tendency which dissimilar bodies have to adhere or stick together.

AERATION, from ἀὴρ, the air; the saturation of a liquid with air.

AERIFORM, from *aer*, the air, and *forma*, a form; having the form of air.

AEROSTATION, from ἀὴρ, the air, and ἵστημι, to weigh; primarily it denotes the science of weights suspended in the air, but in the modern application of the term it signifies the art of navigating the air.

AFFINITY, from *ad*, to, and *finis*, a boundary; relationship; the force which causes dissimilar particles of matter to combine together so as to form new matter.

ALBUMEN, -**INOUS**, from *albumen*, the white of an egg; an important animal principle. The white of an egg is albumen mixed with water.

ALCOHOL, from a word of Arabic origin; the intoxicating ingredient of spirituous liquors.

ALKALI, a soluble body, with a hot, caustic taste, which possesses the power of destroying acidity; the term is derived from *kali*, the Arabic name of a plant, from the ashes of which one species is obtained, and the article *al*.

Alumina, the base of alum; pure clay.

Amalgam, from ἅμα, together, and γαμέω to marry; a chy ical term, signifying the union of any metal with m cury, which is a solvent of various metals.

Amorphous, from ἀ, not, and μορφὴ, a form; not possessi regular form.

Analogy, -**ical**, and -**ous**, from ἀνὰ, thoroughly, and λόγ a relation or proportion; a likeness or resembla between things with regard to their circumstance effects.

Analysis, from ἀνὰ, thoroughly, and λύω, to loosen; separation of a whole into parts.

Angle, from *angulus*, a corner; the inclination of two strai lines to each other, which meet together, but are no the same straight line.

Anhydrous, from ἀ, not, and ὕδωρ, water; containing no ter.

Anion, from ἀνὰ, up, and εἶμι, to go; that which goes a substance which in electrolysis passes to the Anc

Anode, from ἀνὰ, up, and ὁδὸς, a way; the way which sun rises; the surface at which the electricity pas into a body, supposing the currents to move in the parent direction of the sun.

Anomaly, -**lous**, from ἀ, not, and νόμος, a law; an irregu ity or deviation from a law.

Antagonism, from ἀντὶ, against, and ἀγωνίζομαι, to conte opposition of action.

Antagonist, one who contends against another.

Antiseptic, from ἀντὶ, against, and σήπω, to make rott possessing the power of preventing putrefaction.

Approximate, -**ively**, from *ad*, to, and *proximus*, neare having affinity with; bordering upon.

Aqua Regia, i. e., **Regal Water**, a mixture of nitric muriatic acids; so called from its property of dissolv gold, held by the alchymists to be *the king of the m als*.

Aqueo, from *aqua*, water; when prefixed to a word, deno that water enters into the composition of the substa which it signifies.

Arc, from *arcus*, a bow; a part of a curved line, as of a cle, ellipse, &c.

Armature, from *armo*, to arm; a piece of soft iron appl to a loadstone, or connecting the poles of a horseshoe magnet.

Astatic Needle, from ἄστατος, balanced; a double magnetic needle, not affected by the earth's magnetism.

Astronomy, from ἄστρον, a star, and νόμος, a law or rule; the science which treats of the heavenly bodies, their motions, periods, &c., and the causes on which they depend.

Athermanous, from ἀ, not, and θέρμος, heat; that through which heat will not pass is said to be athermanous.

Atmosphere, -ic, from ἀτμός, vapour, and σφαῖρα, a sphere; the sphere of air which surrounds the globe.

Atom, -ic, from ἀ, not, and τέμνω, to cut; a minute particle not susceptible of farther division.

Attraction, -ive, from *ad*, to, and *traho*, to draw; the tendency which bodies have to approach each other.

Austral, from *auster*, the south; southern.

Axis, in geometry, the straight line in a plane figure, about which it revolves to produce or generate a solid: more generally the right line conceived to be drawn from the vertex of a figure to the middle of the base.

Azote, from ἀ, not, and ζωή, life; another name for nitrogen (which see). It is so called because it will not support respiration.

B.

Barium, from βαρὺς, heavy; a metallic substance of dark gray colour, hitherto produced in very small quantities from Baryta.

Barometer, -rical, from βάρος, weight, and μέτρον, a measure; an instrument for measuring the varying weight of the atmosphere.

Baryta; a compound of oxygen, and Barium, possessing alkaline qualities.

Bibulous, from *bibo*, to drink; that which has the quality of drinking in moisture.

Bifurcation, from *bis*, twice, and *furca*, a fork; a forking or division into two branches.

Binary, from *bis*, twice; containing two units.

Binaxial, from *bis*, twice, and *axis*, an axis; having two axes.

Bitumen, -minous, from *bitumen*, pitch; the name given to several inflammable substances, which, though of vogetable origin, are found in the earth, or issue f surface.

Boreal, from *boreas*, the north; northern.

Boron; a dark, olive-coloured substance, obtained fr racic acid, insoluble in water, and a non-cond electricity.

Bromine, from βρῶμος, a strong odour; a liquid of a r brown colour, which possesses a suffocating od pungent taste.

C.

Caloric, from *calor*, heat; an imaginary fluid substan posed to be diffused through all bodies, and th ble effect of which is called heat.

Calorific; imparting the sensation and other effects

Calorimeter, from *calor*, heat, and *metrum*, a measu instrument for measuring caloric.

Capillary, from *capillus*, a hair; resembling or hav form of hairs.

Capsule, from *capsula*, a little chest; a small shallow

Carbon, from *carbo*, a coal; the chymical name for ch

Catalysis, from κατὰ, thoroughly, and λύω, to loos imaginary force which is supposed to assist the position of some bodies, and the composition of

Cathode, from κατὰ, downward, and ὁδὸς, a way; th which the sun sets; the surface at which ele passes out of a body, supposing the current to m the apparent direction of the sun.

Cation, from κατὰ, down, and εἶμι, to go; that whi down; a substance which in electrolysis passe Cathode.

Caustic, from καίω, to burn; possessing the power c ing.

Chlorine, from χλωρὸς, green; a yellowish-green c gas, of a pungent smell, and most injurious to tion.

Chymistry, -ical, from an Arabic word, signifying the edge of the substance or constitution of bodi science whose object it is to examine the cons of bodies.

Circulation; motion in a circle.

RCUMFERENCE, -TIAL, from *circum*, around, and *fero*, to bear; the line which is the boundary of a circle.

EAVAGE, PLANE OF; the plane in which crystals have a tendency to separate.

ERCIBLE, from *coerceo*, to restrain; susceptible of restraint.

HESION, -IVE, from *cum*, together, and *hæroe*, to stick; the relation among the component parts of a body, by which they cling together.

LANDER, from *colo*, to strain; a kind of strainer.

MBUSTION, from *comburo*, to burn; the disengagement of light and heat which accompanies chymical combination.

MPLEMENTARY, from *compleo*, to fill; that which is capable of filling up, so as to make the entire measure of, a quantity.

NCAVE, from *concavus*, hollow; curved inwardly or hollow.

NDUCTION, from *con*, together, and *duco*, to lead. The power of transmitting caloric without change in the relative position of the particles of the conducting body.

NE, -ICAL, and -IC; a solid figure, having a circular base, and its other extremity or vertex terminated by a point.

NGELATION, from *con*, together, and *gelo*, to freeze; the process of freezing.

NGERIES, from *congeries*, a heap; a mass of bodies heaped up together.

NSTITUENT, from *constituo*, to put together; that of which anything consists or is made up.

TACT, from *con*, together, and *tango*, to touch; the relative state of two things which touch one another, but do not cut.

TRACTION, from *con*, together, and *traho*, to draw; the state of being drawn into a narrow compass.

VERGENT, from *con*, together, and *vergo*, to bend; tending to one point from various parts.

VECTION, from *con*, together, and *veho*, to carry; the power in fluids of transmitting heat or electricity by currents.

VEX, from *con*, together, and *veho*, to carry; curved outwardly, or protuberant.

PUSCULAR, from *corpus*, a body; composed of, or relating to atoms.

Coruscation, from *corusco*, to flash or shine; a flash, or quick vibration of light.

Crucible, from *crux*, *crucis*, a cross; a little pot such as goldsmiths melt their gold in; so called from having a cross impressed upon it.

Cryophorus, from *κρύος*, cold, and *φέρω*, to produce; an instrument for showing the relation between evaporation at low temperatures and the production of cold.

Crystallography, from *κρύσταλλος*, a crystal, and *γράφω*, to describe; the science which treats of crystals.

Crystals, -line, from *κρύσταλλος*, ice; a substance having a regular form, as rock crystal, which resembles ice.

Crystallization; the formation of crystals during the passage of certain bodies from a fluid to a solid form.

Cube, -ic; a solid figure contained by six equal squares.

Cyanogen, from *κύανος*, blue, and *γεννάω*, to produce; a colourless gas, which burns with a peculiar purple flame; it is the essential ingredient in the pigment called " Prussian blue."

Cyanuret or **Cyanide**; the compounds of Cyanogen, which are not acid.

Cylinder, -rical; a solid figure described by the revolution of a right-angled parallelogram, about one of its sides which remains fixed.

D.

Decomposition; the resolution of a compound body into its component parts.

Decrement, from *decresco*, to grow less; the quantity by which anything decreases or becomes less.

Deduction, from *de*, down, and *duco*, to lead; the process of reasoning by which we infer particular from general truths.

Deflagration, from *deflagro*, to burn; burning.

Deflection, from *de*, from, and *flecto*, to bend; a turning aside out of the straight way.

Degree, from *de*, down, and *gradus*, a step; a quantity in measurement, as, in geometry, the 360th part of the circumference of a circle.

Deliquescence, from *deliqueo*, to melt; a gradual melting, caused by the absorption of water from the atmosphere.

DENSITY, from *densus*, thick; vicinity or closeness [illegible] parts.

DEPHLOGISTICATED; deprived of phlogiston, the supposed principle of inflammability.

DETONATION, from *detono*, to thunder; explosion accompanied with noise.

DIAGRAM, from *διαγράφω*, to delineate; a delineation or representation of geometrical and other figures.

DIAMETER, from *διὰ*, through, and *μέτρον*, [illegible] line which passes through the centre of a circle, [illegible] any other curvilinear figure.

DIAPHANOUS, from *διὰ*, through, and [illegible] which allows a passage to the rays of light.

DIAPHRAGM, from *διὰ*, division, and *φράσσω*, [illegible] separation between two things.

DIATHERMANOUS, from *διὰ*, through, and [illegible] through which heat will pass is said to [illegible] nous.

DIELECTRIC, from *διὰ*, through, and [illegible] substance through which electricity [illegible] ted.

DIFFRACTION, from *dis*, signifying division, and [illegible] break; the deviation of rays of light from their [illegible] course, when made to pass by the boundary [illegible] opaque body.

DILATATION, from *differo*, to bear apart; the [illegible] into greater space.

DIMORPHOUS, from *δίς*, twice, and *μορφή*, a form; having [illegible] forms.

DISC, from *discus*, a quoit; the apparent surface of a [illegible] body.

DISINTEGRATION, from *dis*, meaning separation, and [illegible] whole; an utter separation of particles.

DISPERSION, -**IVE**, from *di*, in different directions, and [illegible] to scatter; the act of scattering.

DISRUPTION, from *dis*, in different directions, and *rumpo*, to break; the act of tearing asunder.

DISSECTION, from *disseco*, to cut in pieces; the act of separating into pieces.

DISTILLATION, separation drop by drop; the process by which a fluid is separated from another substance, by heat being converted into vapour, and afterward condensed drop by drop.

DIVELLENT, from *divello*, to tear asunder; that which causes separation.

DIVERGENT, from *di*, in different directions, and *vergo*, to bend; tending to various parts from one point.

DODECAHEDRON, from *δώδεκα*, twelve, and *ἕδρα*, a base or side; a solid figure contained by twelve equal sides.

DYNAMICS, -ICAL, from *δύναμις*, power; that branch of mechanical science which treats of moving powers, and of the action of forces on solid bodies, when the result of that action is motion.

E.

EBULLITION, from *ebullio*, to boil; the act of boiling.

EDUCT, from *e*, out of, and *duco*, to draw; anything separated from another with which it previously existed in combination.

EFFLORESCENCE, from *effloresco*, to blow as a flower; the formation of small crystals on the surfaces of bodies, in consequence of the abstraction of moisture from them by the atmosphere.

ELASTICITY, -IC, from *ἐλαύνω*, to push or thrust; the property bodies possess of resuming their original form when pressure is removed.

ELECTRICITY, from *ἤλεκτρον*, amber; the name of a power of matter, which produces a variety of peculiar phenomena, the first of which were observed in the mineral substance called amber; the laws, hypothesis, and experiments by which they are explained and illustrated, constitute the science of electrity.

ELECTRODE, from *ἤλεκτρον*, electricity; and *ὁδός*, a way; the point at which an electric current enters or quits the body through which it passes.

ELECTROLYSIS, -LYTE, &c., from *ἤλεκτρον*, electricity, and *λύω*, to loosen; the act of decomposing bodies by electricity.

ELECTRO-MAGNETISM; magnetism produced by electricity.

ELECTROMETER; an instrument for ascertaining the quality and quantity of electricity in electrified bodies.

ELECTROPHORUS; an instrument for producing electricity.

ELECTROSCOPE; an instrument for exhibiting the attractive and repulsive agencies of electricity.

ELEMENT, -ARY, from *elementum*, an element; that which cannot be resolved into two or more parts, and contains but one kind of ponderable matter.

ELLIPSE, from ἐκ, deficiently, and λείπω, to leave; one of the conic sections formed by the intersection of a plane and a cone, when the plane makes a less angle with the base than that formed by the base and the side of the cone.

EMANATION, from *e*, out, and *mano*, to flow; that which issues from any substance or body.

EMPIRICAL, from ἐν, in, and πειράομαι, to make trial; that which is made or is done as an experiment, independently of hypothesis or theory.

EMPYREUMATIC, from ἐν, in, and πῦρ, fire; having the taste or smell of burned animal or vegetable substances.

ENDOSMOSE, from ἔνδον, within, and ὠσμὸς, the act of pushing; a flowing from the outside to the inside.

EPIDERMIS, from ἐπὶ, upon, and δέρμα, the skin; the exterior layer of the skin.

EQUATOR, from *æquus*, equal; a great circle of the sphere, equally distant from the two poles; when the sun is in this circle, the days and nights are equal in all parts of the world.

EQUILIBRIUM, from *æquus*, equal, and *libra*, a balance; the state of rest produced by forces equally balancing one another.

EQUIVALENT, from *æquus*, equal, and *valeo*, to be worth; equal in value.

ETIOLATION; the blanching of vegetables by exclusion from light.

EVAPORATION, from *e*, out, and *vapor*, vapour; the conversion of a liquid into vapour.

EXOSMOSE, from ἔξω, without, and ὠσμὸς, the act of pushing; a flowing from inside to the outside.

EXPANSION, from *expando*, to open out; the enlargement or increase in the bulk of bodies, which is produced by heat.

EXPERIENCE, from *experior*, to attempt, to try; knowledge gained by observation.

EXPERIMENT; something done in order to discover an uncertain or unknown effect.

EXPLOSION, from *ex*, out, and *plaudo*, to utter a sound; a sudden expansion of an elastic fluid with force, and a loud report.

EXTRANEOUS, from *extra*, without; foreign and contrary to the nature of a thing.

F.

FELLY; the exterior rim of a wheel, supported by the spokes.

FERRUGINOUS, from *ferrum*, iron; of iron.

FILTER; a strainer.

FILTRATION; the process whereby liquids are strained.

FLEXURE, from *flecto*, to bend; the act of bending; also the bend or curve of a line or figure.

FLUORINE, from *fluo*, to flow; an elementary principle of fluor spar, which is so called from its acting as a flux in the working of minerals.

FOCUS, -CAL, from *focus*, a fireplace; a point in which a number of rays of light or heat meet after being refracted or reflected.

FORMULA, a general theorem; it is called Algebraic, Logarithmic, &c., according to the branch of mathematics to which it relates.

FRICTION, from *frico*, to rub; the rubbing or grating of the surfaces of bodies upon one another; also the retarding force caused by this rubbing of surfaces together.

G.

GALVANISM, from Professor GALVANI; current electricity is sometimes so called.

GALVANOMETER; an instrument for measuring galvanism.

GAS, -EOUS; a term first introduced by VAN HELMONT; a permanent aeriform fluid.

GELATINOUS, from *gelo*, to freeze; resembling jelly.

GONIOMETER, from γωνία, an angle, and μέτρον, a measure; an instrument for measuring angles.

GENUS, -ERIC, from *genus*, a whole race or kind

GEOMETRY, -ICAL, from γῆ, the earth, and μέτρον, a measure; the science which treats of the relative magnitudes of extended bodies.

Gravitation, from *gravis*, heavy: the abstract power which draws bodies towards each other's centres.

Gravity, from *gravis*, heavy: the natural tendency of bodies to fall towards a centre.

Gravity, Specific: the relative gravity of a body considered with regard to some other body, which is assumed as a standard of comparison.

H.

Halo, from *ἅλως*, a crown: a luminous circle; appearing occasionally around the heavenly bodies; but more especially about the sun and moon.

Heliographic, from *ἥλιος*, the sun, and *γράφω*, to write; delineated by the sun.

Helix, from *ἑλίσσω*, to twist round; a screw or spiral.

Hemisphere, from *ἥμισυς*, half, and *σφαίρα*, a sphere; the half of a sphere formed by a plane passing through the centre.

Hermetic Seal; when the neck of a glass vessel or tube is heated to the melting point, and then twisted with pincers until it be air-tight, the vessel or tube is said to be hermetically sealed, or to have received the seal of Hermes, the reputed inventor of chymistry.

Heterogeneous, from *ἕτερος*, different, and *γένος*, kind; different in nature and properties.

Homogeneous, from *ὁμὸς*, alike, and, *γένος*, kind; alike in nature and properties.

Horizontal, from *ὁρίζω*, to bound or terminate; parallel to the horizon.

Hydrate, from *ὕδωρ*, water; any uncrystallized substance which contains water in a fixed definite proportion.

Hydrogen, from *ὕδωρ*, water, and *γεννάω*, to produce; an inflammable, colourless, and aeriform fluid; the lightest of all known substances, and one of the elements of water.

Hydro; when prefixed to the name of a chymical substance, denotes that hydrogen enters into the composition of the substance which it signifies.

Hydrometer, from *ὕδωρ*, water, and *μέτρον*, a measure; an instrument for comparing the density and gravity of liquids with water.

Hydrostatics, from *ὕδωρ*, water, and *στατὸς*, standing; that branch of Natural Philosophy which treats of the pressure and equilibrium of non-elastic fluids, and also of the weight, pressure, &c., of solids immersed in them.

HYGROMETER, from ὑγρὸς, moist, and *μέτρον*, a measure; an instrument for ascertaining accurately the quantity of moisture in the atmosphere.

HYGROSCOPE, from ὑγρὸς, moist, and *σκοπέω*, to consider; an instrument for exhibiting approximatively the moisture of the atmosphere.

HYPERBOLA, from ὑπὲρ, excessively, and *βάλλω*, to place; one of the conic sections formed by the intersection of a plane and a cone, when the plane makes a greater angle with the base of the cone than that formed by the base and the side of the cone.

HYPO, from ὑπὸ, under; when prefixed to a word, denotes an inferior quantity of some ingredient which enters into the composition of the substance which it signifies.

HYPOTHESIS, -TICAL, from ὑπὸ, under, and *τίθημι*, to place; a principle supposed or taken for granted in order to prove a point in question.

I.

IMMEDIATELY, from *im*, without, and *medius*, intervening; without the intervention of a second cause.

IMPINGING, from *impingo*, to strike against; dashing against.

INCANDESCENT, from *incandesco*, to grow white; white o glowing with heat.

INCIDENCE, from *in*, upon, and *cado*, to fall; the direction i which one body falls on or strikes another; the angl which the moving body makes with the plane of th body struck, is called the "angle of incidence."

INCREMENT, from *incresco*, to increase; the quantity by whic anything increases or becomes greater.

INDUCTION, -IVE, from *in*, to, and *duco*, to lead; the proces of reasoning, by which we are led from general to particular truths.

INDUCTION, ELECTRICAL; the effect produced by the tendency of an insulated electrified body to excite an opposite electric state in neighbouring bodies.

INDUCTOMETER; an instrument for measuring electrical induction.

INERTIA, from *inertia*, inactivity; the disposition of matter to remain in its state of rest or motion.

INFLAMMABLE, from *in*, and *flamma*, a flame; capable of burning with a flame.

INFLECTION, from *in*, to, and *flecto*, to bend; the same as Diffraction; which see.

INSULATION, from *insula*, an island; when a body, containing a quantity of free heat, or of electricity, is surrounded by non-conductors, it is said to be *insulated*.

INTEGRANT, from *integer*, whole, entire; those parts of a body which are of the same nature with the whole, are called integrant.

INTERSTICES, from *interstitium*, a break or interval; the unoccupied spaces between the molecules of bodies.

IODIDE, from ἴον, a violet, and εἶδος, the form or likeness; a compound of iodine which is not used.

IODINE; a soft opaque substance of a bluish-black colour; when heated it gives off a violet-coloured gas.

IRIDESCENT, from *Iris*, the rainbow; marked with the colours of the rainbow.

ISOCHRONOUS, from ἴσος, equal, and χρόνος, time; performed in equal times.

ISOMERIC, from ἴσος, equal, and μέρος, a part; substances which consist of the same ingredients, in the same proportion, and yet differ essentially in their properties, are called Isomeric.

ISOMERISM; that portion of Chymical Science which treats of Isomeric substances.

J.

JUXTAPOSITION, from *juxta*, near, and *pono*, to place; the placing of one thing close to another.

L.

LAMINÆ, from *lamina*, a thin plate; extremely thin plates, of which some solid bodies are composed.

LENS, from *lens*, a bean; properly a small glass in the form of a bean; but more generally it means a piece of glass, or other transparent substance, having its two surfaces so formed that the rays of light, in passing through it, have their direction changed, and are made to diverge or converge, or to become parallel after diverging or converging.

LEVIGATION, from *lævis*, smooth; the art of reducing to a light powder.

LIGNIN, from *lignum*, wood; the fibrous structure of vegetable bodies, which remains when all the substances which are soluble have been removed.

LIQUEFACTION, from *liquefacio*, to make liquid; the process of converting into a liquid state.

LITMUS; a blue pigment obtained from the *Lichen rocella*; it is a most delicate test of acids, which turn it red.

LOADSTONE, i. e., LEADSTONE; an ore of iron having magnetic properties.

LOGOMETRIC, from λόγος, a proportion, and μέτρον, measure; measuring proportionate spaces.

M.

MAGNET, from *Magnesia*, a town in Asia Minor; artificial magnets are small bars of steel or iron, which, when placed at liberty, turn one end to the north.

MAGNETISM; the peculiar property possessed by certain ferruginous bodies, whereby, under certain circumstances, they attract and repel one another according to certain laws.

MAGNETO-ELECTRICITY; electricity produced by magnetism.

MALLEABLE, from *malleus*, a hammer; that which is capable of being spread by beating.

MANUFACTURE, from *manus*, the hand, and *facio*, to make; literally, anything made by the hand.

MASS, -IVE; the quantity of matter in a body which is in proportion to the weight.

MATHEMATICS, -AL, from μανθάνω, to learn; the science which treats of the ratios of numbers and quantities.

MAXIMUM, from *maximus*, greatest; the greatest value of a variable quantity.

MECHANICS, from μηχανὴ, a machine; the science which treats of the laws of the rest and motion of bodies.

MEDIATELY, from *medius*, intervening; with the intervention of a second cause.

MERIDIAN, from *meridies*, midday; the *terrestrial meridian* of a station on the earth's surface, is the great circle passing through both the poles of the earth and through the place.

Metallurgy, from *μέταλλον*, a metal, and *ἔργον*, a work; the art of working metals, and separating them from their ores.

Metaphysics, -ical, from *μετὰ*, beyond, and *φύσις*, nature; the science which treats of objects inaccessible to the senses.

Methylene, from *μέθυ*, wine; a compound resembling alcohol in its constitution.

Mineralogy; the science which treats of bodies not being vegetable or animal.

Minimum, from *minimus*, least; the least value of a variable quantity.

Moiree Metallique, from *moirée*, a watered silk; when tin plates are washed over with a weak acid, the crystalline texture of the tin becomes apparent, forming a crystalline appearance, which has been called Moirée Métallique.

Molecules, -ar, a diminutive from *moles*, a mass; the infinitely small material particles of which bodies are conceived to be aggregations.

Momentum, from *moveo*, to move; the product of the numbers which represent the quantity of matter and the velocity of a body, is called its momentum or quantity of motion.

Mucilaginous; resembling mucilage or gum.

Multiple, from *multiplico*, to render manifold; a quantity is said to be a multiple of another when it contains that other quantity a certain number of times without a remainder.

N.

Nascent, from *nascor*, to be born; in the moment of formation.

Negative, from *nego*, to deny; quantities to which the sign of subtraction or negative sign is prefixed, are called negative quantities; this sign is also used to denote operations which are the reverse of those denoted by the positive sign.

Nitrogen, from *νίτρον*, nitre, and *γεννάω*, to produce; a colourless gas, devoid of taste or smell; it is one of the constituents of the atmosphere.

Nodes, -al, from *nodus*, a knot; in the doctrine of curves, a node is a small oval figure made by the intersection of one branch of a curve with another.

Normal, from *norma*, a rule; according to rule.

Nucleus, from *nucleus*, a kernel; the central parts of a body which are supposed to be firmer, and separated from the other parts, as the kernel of a nut is from the shell; also, the point about which matter is collected.

O.

Oblate, from *ob*, in front of, and *latus*, broad; flattened or shortened.

Oblong, from *ob*, in front of, and *longus*, long; greater in length than in breadth.

Octohedron, -al, from ὀκτὼ, eight, and ἕδρα, a side; a solid figure contained by eight equal and equilateral triangles.

Olefiant Gas, from *oleum*, oil, and *fio*, to become; a colourless, tasteless gas, which derives its name from its property of forming an oil-like liquid with chlorine.

Optics, from ὄπτομαι, to see; that branch of Natural Philosophy which treats of vision, and of the nature and properties of light, and of the various changes it undergoes.

Organic Matter, from ὄργανον, an organ; when matter possesses organs, or organized parts for sustaining living action, as animals and plants, it is called organic.

Organization; construction in which the parts are so disposed as to be subservient to each other.

Oscillation, from *oscillor*, to swing; the vibration or reciprocal ascent and descent of a pendulum.

Oxyde; a combination with oxygen, not being acid.

Oxydizable; capable of being converted into an oxyde.

Oxygen, from ὀξὺς, acid, and γεννάω, to produce; a colourless, aeriform fluid, which was formerly supposed to be the universal acidifying principle.

P.

Parabola, from παρὰ, parallel to, and βάλλω, to place; one of the conic sections, formed by the intersection of a plane and a cone, when the plane passes parallel to the side of the cone.

Parallel; a term applied in geometry to lines and planes, which are everywhere equidistant from one another; straight lines, which, if infinitely produced, never meet, are called parallel straight lines.

Parallelogram; a four-sided figure, of which the opposite sides are parallel and equal.

Parallelopipedon; a solid figure contained by six parallelograms, the opposite sides of which are equal and parallel.

Pellicle, a diminutive from *pellis*, a skin or crust; a thin crust formed on the surface of a solution by evaporization.

Pendulum, from *pendeo*, to hang; a heavy body so suspended that it may vibrate, or swing backward and forward about some fixed point, by the action of gravity.

Percolate, from *per*, through, and *colo*, to strain; to strain through.

Permeate, from *permeo*, to pass through; to penetrate.

Perpendicular; the straight line which, standing upon another straight line, makes the adjacent angles equal, and consequently right angles, is said to be perpendicular to the line upon which it stands.

Phenomenon, from *φαίνομαι*, to appear; an appearance.

Philosophy, -**ical**, from *φιλέω*, to love, and *σοφία*, wisdom; the study or knowledge of nature or morality, founded on reason and experience, the word originally implying "A love of wisdom."

Phlogiston, from *φλέγω*, to burn; a name given by the older chymists to an imaginary substance, which was considered as the principle of inflammability.

Phosgene, from *φῶς*, light, and *γεννάω*, to produce; produced by light.

Phosphorus, from *φῶς*, light, and *φέρω*, to produce; a highly inflammable substance, obtained from calcined bones, which emits light when placed in the dark.

Photometer, from *φῶς*, light, and *μέτρον*, a measure; an instrument for measuring the different intensities of light.

Physics, -**ical**, from *φύσις*, nature; the science of natural bodies, their phenomena, causes, and effects, with th affections, motions, and operations.

PHYSIOLOGY, -ICAL, from φύσις, nature, and λόγος, an account; the science which treats of the structure of living beings.

PLUMMET, from *plumbum*, lead; a weight suspended from a string to mark the direction of gravity on a perpendicular to the earth.

PNEUMATICS, from πνεῦμα, air; that branch of Natural Philosophy which treats of the weight, pressure, and elasticity of aeriform fluids.

POLARITY; the opposition of two equal forces in bodies, similar to that which confers the tendency of magnetized bodies to point to the magnetic poles.

POLARIZATION; the communication of the above opposition of forces.

POLARIZED LIGHT; light which, by reflection or refraction at a certain angle, or by refraction in certain crystals, has acquired the property of exhibiting opposite effects in planes at right angles to each other, is said to be polarized.

POLES; the extremities of the axis about which a body revolves.

POLES OF A MAGNET; points in a magnet where the intensity of the magnetic force is a maximum; one of these attracts, and another repels the same pole of another magnet.

PORES, from πόρος, a passage; the small interstices between the solid particles of bodies.

PRECIPITATION, from *præcipito*, to fall suddenly; the separation of a solid from a liquid; a triangular glass solid used for the separation of rays of light by refraction.

PRODUCT, from *pro*, forth, and *duco*, to draw; anything formed from the elements of another by an operation.

PROGRESSION, from *pro*, forward, and *gradior*, to step; a series of quantities advancing in the same manner or according to the same law; in an arithmetic progression, they increase or decrease by a common difference; in a geometric by a common ratio.

PROJECTILE, from *pro*, forward, and *jacio*, to throw; a heavy body projected, or cast forward into space, by any external force.

Proportion; the relation of equality subsisting between two ratios.

Protractor, from *pro*, forward, and *traho*, to draw; an instrument for protracting or laying down on paper the angles of a figure.

Pyrometer, from πῦρ, fire, and μέτρον, a measure; an instrument for measuring higher degrees of temperature than can be ascertained by a thermometer.

Pyroxylic Spirit, from πῦρ, fire, and ὀξὺς, acid; a colourless transparent spirit obtained by the destructive distillation of wood.

Pyro; when prefixed to a word, denotes that the substance which it signifies has been formed at a high temperature.

Q.

Quadrant; the fourth part of the circumference of a circle.

Qualitative; regarding the properties of a body without reference to quantity.

Quantitative; regarding quantities.

R.

Radiation, from *radius*, a ray; the shooting forth in all directions from a centre.

Radical, from *radix*, a root; the original principle of a compound.

Radius; the straight line drawn from the centre to the circumference of a circle.

Rarefaction, from *rarus*, rare, and *facio*, to make; the act of causing a substance to become less dense; it also denominates the state of this lessened density.

Ratio; the relation which subsists between two quantities of the same kind, the comparison being made by considering what multiple part or parts one of them is of the other.

Ray; a beam of light propagated from a radiant point.

Reaction; the reciprocation of any impulse, or force impressed, made by the body on which such impression is made. Reaction is always equal to action.

Recondite, from *recondo*, to hide; hidden or concealed.

Rectangle, from *rectus*, right, and *angulus*, an angle; a four-sided plane figure, in which all the angles are right angles, and its opposite sides equal and parallel.

Rectification; the process of drawing anything off by distillation, in order to make it more pure and refined.

Rectilinear; consisting of, or bounded, by straight lines.

Reflection, from *re*, back, and *flecto*, to bend; the act of bending back; when rays of light fall on the surfaces of bodies, part of them are thrown back or reflected.

Refraction, from *re*, back, and *frango*, to break; the deviation of rays of light from their direct course, when passing through media of different densities.

Refrangible; susceptible of refraction.

Refrigeration, from *re*, again, and *frigo*, to cool; the act of cooling.

Repulsion, from *re*, back, and *pello*, to drive; that property in certain bodies whereby they mutually tend to recede and fly off from each other.

Retort, from *re*, back, and *torqueo*, to twist; a vessel with a bent neck, which is made use of in chymical operations.

Rhombus; a figure which has all its sides equal, but its angles are not right angles.

Rhombohedron; a solid figure, whose sides are composed of rhombi.

Rhomboid; a figure which has its opposite sides equal, but all its angles are not equal, neither are all its angles right angles.

S.

Salifiable Bases, from *sal*, salt, and *fio*, to become; bodies capable of combining with acids to form salts.

Sapid, from *sapio*, to taste of; possessing the power of exciting the organs of taste.

Saturation, **-ated**, from *satur*, full; the solution of one body in another until the receiving body can contain no more.

Scale, from *scala*, a ladder; an instrument in which a line is divided into small and equal parts, and which is applied for the purpose of ascertaining the relative dimensions of other lengths not so divided.

Section, from *seco*, to cut; a cutting, or part separated from the whole.

Segment of a Circle; any portion cut off by a straight line.

Selenium, from σελήνη, the moon; an inflammable solid body of a reddish brown colour; it is tasteless, and possesses metallic lustre.

Sine; the straight line, drawn from one extremity of an arc, perpendicular to the radius which passes through the other extremity.

Solution, from *solvo*, to loosen; in chymical language, any fluid which contains another substance dissolved in, and intimately mixed with it.

Solvent; any substance which will dissolve another.

Specific, from *species*, a particular sort or kind; that which denominates any property which is not general, but is confined to an individual or species.

Spectrum; the coloured image formed on a white surface by rays of light passing through a hole, and being refracted by a glass prism.

Sphere; the solid figure formed by the rotation of a semicircle about its diameter.

Spheroid, -al; a solid figure, formed by the revolution of an ellipse about one of its axes; hence it is sometimes called an ellipsoid; the spheroid will be oblate or prolate, according as the revolution is performed about the minor or major axis of the ellipse.

Statics, -ical, from στατὸς, standing; that branch of mechanical science which treats of the equilibrium, pressure, weight, &c., of solid bodies when at rest.

Stratum, from *sterno*, to strew; a layer.

Symmetry, -ical, from σὺν, together, and μέτρον, a measure; conformity of measure.

Synthesis, from σὺν, together, and, τίθημι, to place; the composition of a whole from its parts; in mathematics, the process of reasoning out new principles from those already established.

Sublimation, from *sublimis*, high; the act of raising into vapour by means of heat, and condensing in the upper part of a vessel.

Sulphuret; a combination of a metal with sulphur.

Synchronous, from σὺν, together, and χρόνος, time; performed in the same time.

T.

Tactile, from *tango*, to touch; of or relating to touch.

Tangent, -ial; the line which touches a circle or any other curve, but does not cut it.

Tentative, from *tento*, to try; experimental.

Ternary, from *ter*, thrice; containing three units.

Tetrahedron, from *τέσσαρες*, four, and *ἕδρα*, a base or side; a solid figure contained by four equal and equilateral triangles.

Theory, -etical, from *θεωρία*, a view; a collected view of all that is known on any subject into one.

Thermo-Electricity; electricity produced by heat.

Thermometer, from *θέρμος*, heat, and *μέτρον*, a measure; an instrument for measuring the degrees of heat.

Thermoscope, from *θέρμος*, heat, and *σκοπέω*, to view; an instrument for exhibiting the powers of heat.

Tire; a hoop of iron used to bend and receive the felly of a wheel.

Torsion, Force of, from *torqueo*, to twist; a term applied by Coulomb to denote the effort made by a thread which has been twisted to untwist itself.

Transparent; a term to denote the quality of a substance which not only admits the passage of light, but also of the vision of external objects.

Triturated, from *trituro*, to thrash; reduced to powder.

Truncation, from *truncus*, cut short; the cutting off a portion of a solid, as of the solid angle of a crystal.

U.

Undulation, from *unda*, a wave; a formation of waves.

Uniaxal, from *unus*, one, and *axis*, an axis; having but one axis.

V.

Vacuum, Latin; a space empty and devoid of all matter.

Ventilation, from *ventus*, wind; the supply of fresh air.

Vernier; an instrument invented by Vernier; it consists of a small moveable scale, running parallel to the fixed scale of a quadrant or other instrument, and having the effect of subdividing the divisions of the instrument into more minute parts.

Vibration, from *vibro*, to brandish; the regular reciprocating motion of a body, as of a pendulum, &c.; a motion to and fro.

Volume, from *volumen*, a roll; the apparent space occupied by a body.

W.

Weight; the pressure which a body exerts vertically downward in consequence of the action of gravity.

Z.

Zero; the numeral 0, which fills the blank between the ascending and descending numbers in a series.

THE END